Southeast Regional Carbon Sequestration Partnership (SECARB)

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Abstract

The Southeast Regional Carbon Sequestration Partnership's (SECARB) Phase I program focused on promoting the development of a framework and infrastructure necessary for the validation and commercial deployment of carbon sequestration technologies. The SECARB program, and its subsequent phases, directly support the Global Climate Change Initiative's goal of reducing greenhouse gas intensity by 18 percent by the year 2012.

Work during the project's two-year period was conducted within a "Task Responsibility Matrix." The SECARB team was successful in accomplishing its tasks to define the geographic boundaries of the region; characterize the region; identify and address issues for technology deployment; develop public involvement and education mechanisms; identify the most promising capture, sequestration, and transport options; and prepare action plans for implementation and technology validation activity.

Milestones accomplished during Phase I of the project are listed below:

- Completed preliminary identification of geographic boundaries for the study (FY04, Quarter 1);
- Completed initial inventory of major sources and sinks for the region (FY04, Quarter 2);
- Completed initial development of plans for GIS (FY04, Quarter 3);
- Completed preliminary action plan and assessment for overcoming public perception issues (FY04, Quarter 4);
- Assessed safety, regulatory and permitting issues (FY05, Quarter 1);
- Finalized inventory of major sources/ sinks and refined GIS algorithms (FY05, Quarter 2);
- Refined public involvement and education mechanisms in support of technology development options (FY05, Quarter 3); and
- Identified the most promising capture, sequestration and transport options and prepared action plans (FY05, Quarter 4).

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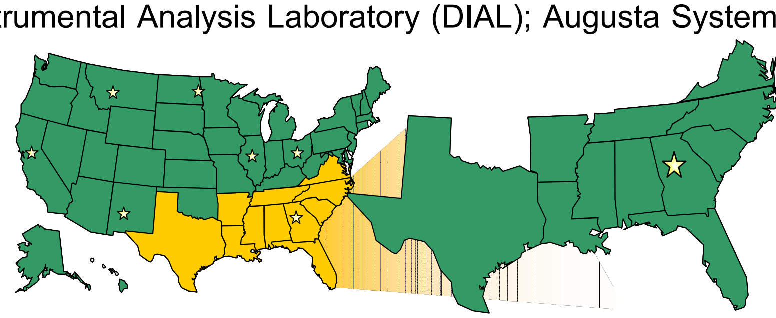
Introduction

The Southeast Regional Carbon Sequestration Partnership successfully completed the majority of its Phase I program work by September 30, 2005 and compiled its findings under a no-cost extension that is open until August 31, 2006. Information received as of June 15, 2006, was used to prepare this Draft Final Report, with the exception of one work element. That work element consists of continued characterization of SECARB states.

On November 21, 2002, Energy Secretary Spencer Abraham announced a new phase of the United States Department of Energy (DOE) research program solely devoted to the development and deployment of viable carbon sequestration technologies. Less than one month later, the Department issued Phase I of a solicitation aimed at creating a nationwide network of regional carbon sequestration partnerships (RCSPs).

Given the Southern States Energy Board's (SSEB) existing carbon management initiative, the SSEB immediately began facilitating discussions with state and federal agencies, policy makers, industry representatives, research entities and other non-governmental organizations to determine a regional response to the solicitation. On August 16, 2003, the Department announced the awardees of the Phase I solicitation. The result is a network of seven regional carbon sequestration partnerships, including the Southern States Energy Board's Southeast Regional Carbon Sequestration Partnership, or SECARB. SECARB is a collaboration covering eleven U.S. states under a DOE initiative to develop regional approaches to carbon sequestration in support of President George W. Bush's Global Climate Change Initiative.

SECARB's work is managed and administered by the Southern States Energy Board. SSEB is the only interstate compact in the United States that is constituted by both federal and state laws, that has governors, state legislators and a Presidential appointee comprising its board of directors and is empowered by its charter to address energy and environmental issues. Under Phase I, the Technical Team partners were SSEB; Electric Power Research Institute (EPRI); a Mississippi State University (MSU) team led by the Diagnostic Instrumental Analysis Laboratory (DIAL); Augusta Systems, Inc.; Massachusetts Institute of Technology (MIT); the University of Texas at Austin, Bureau of Economic Geology (TX BEG); the Virginia Polytechnic Institute and State University (Virginia Tech); Winrock International; Geological Survey of Alabama; Advanced Resources International (ARI); Applied Geo Technologies,



The SECARB region includes eleven states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas and Virginia.
Map courtesy of the U.S. DOE/NETL.

Inc.; a business of the Mississippi Band of Choctaw Indians; the Tennessee Valley Authority (TVA); RMS Strategies; and The Phillips Group.

During the two-year project period, SECARB successfully evaluated options and potential opportunities for regional carbon sequestration, promoted the development of a framework and infrastructure necessary for the validation and deployment of carbon sequestration technologies and produced implementation plans for pilot-scale projects to test and validate approaches and technologies. These plans will guide the work of the Partnership during Phase II of the program, beginning on October 1, 2005. In addition, the Partnership engaged stakeholders from diverse constituencies in the planning and implementation of SECARB activities to ensure that all interests are well represented in this collaboration.

Executive Summary

The SECARB region has a diverse partnership composition that encompasses state executive and legislative leadership; electric utilities and associations; sequestration and GIS research centers; energy producers and associations; and natural resource advocates. Also, the region has a diverse portfolio of carbon dioxide (CO_2) sources, potential CO_2 transport networks and sequestration options.

Work during the two-year Phase I project period was conducted within a “Task Responsibility Matrix.” Under Task 1.0 Define Geographic Boundaries of the Region, SECARB initially identified the region to include Alabama; Arkansas; Florida; Georgia; Louisiana; Mississippi; North Carolina; South Carolina; and Tennessee. During the second quarter of the project, Texas and Virginia were added to the Partnership. No geographical changes occurred during the remainder of the project. Under Task 2.0 Characterize the Region, general mapping and screening of sources and sinks were completed, with integration and GIS mapping. Characterization focused on smaller areas having high sequestration potential. Under Task 3.0 Identify and Address Issues for Technology Deployment, SECARB expanded upon its assessment of safety, regulatory, permitting and accounting frameworks within the region to allow for wide-scale deployment of promising terrestrial and geologic sequestration approaches. Under Task 4.0 Develop Public Involvement and Education Mechanisms, SECARB utilized results of a survey and focus group meeting to refine approaches to educating and involving the public. SECARB technical team members also participated in the U.S. Department of Energy/National Energy Technology Laboratory (NETL) Communications Workshop Series. In addition, SECARB developed a website accessible at www.secarbon.org that will be maintained throughout Phase II.

Under Task 5.0 Identify the Most Promising Capture, Sequestration, and Transport Options, SECARB’s focus shifted from region-wide mapping and characterization to a more detailed screening approach designed to identify the most promising opportunities. Under Task 6.0 Prepare Action Plans for Implementation and Technology Validation Activity, the SECARB team developed an integrated approach to

implementing the most promising opportunities and in setting up measurement, monitoring and verification (MMV) programs for the most promising opportunities.

Experimental

Due to the nature of the project, no experimental methods, materials or equipment were necessary during the SECARB Phase I period.

Results and Discussion

During Phase I, the SECARB team was tasked with (1) defining the geographic boundaries; (2) characterizing the region; (3) identifying and addressing issues for technology deployment; (4) developing public involvement and education mechanisms; (5) identifying the most promising capture, sequestration and transport options; and (6) preparing action plans for implementation and technology validation activities. A summary of the results for each task is provided in this section of the report.

Task 1: Define Geographic Boundaries

Task 1 highlights the similarities of CO_2 sources, sinks, permitting considerations, partners and other features within the region consisting of eleven contiguous states. The initial nine-state region was comprised the states identified in the response to proposal submitted by SSEB on behalf of the southeast region. It included the states of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee. The SECARB membership was expanded within the first six months after award to include two geographic areas that were not included in the seven active partnerships; the Commonwealth of Virginia and the eastern counties of Texas.

Task 1 deliverables included the following information.

1.A. Source and sink data formatted for GIS. A major focus of Phase I was to characterize the CO2 sources and potential sinks within the geographic boundaries of the region. Various team members contributed to the effort and key information on sources and sinks has been provided in GIS format (Deliverables Appendix Document, Volume II, Bookmark 1.A).

1.B. Permitting structures for participating states. SECARB has developed regulatory and permitting information for each participating state (Deliverables Appendix Document, Volume I, Bookmark 1.B). In addition, SECARB participated in cross-cutting activities of the Partnerships related to regulatory, permitting, safety and accounting interests, as well as participating with the Interstate Oil and Gas Compact Commission (IOGCC) regulatory review.

1.C. Description of potential active partners. SECARB is comprised of a broad range of active partners, including state government officials, national laboratories and academic research institutions, non-government organizations, electric utilities, and other industry representatives.

The active research partners in Phase I include, in alphabetical order:

- Applied Geo Technologies;
- Augusta Systems, Inc.;
- Electric Power Research Institute;
- Geologic Survey of Alabama;
- Gulf Coast Carbon Center, University of Texas;
- Massachusetts Institute of Technology;
- Mississippi State University, Diagnostic Instrumentation Analysis Laboratory;
- The Phillips Group;
- RMS Research;
- Southern States Energy Board (lead);
- Susan Rice and Associates, Inc.;
- Tennessee Valley Authority Public Power Institute;
- U.S. Department of Energy, National Energy Technology Laboratory;
- Virginia Tech Center for Coal and Energy Research; and
- Winrock International.

In addition to active research partners, SECARB has the following Technology Coalition Partners:

- Advanced Resources, International;
- AGL Resources;
- American Electric Power;
- Arkansas Oil and Gas Commission;
- Augusta Systems, Inc.;
- BP America;
- CO_2 Capture Project;
- Center for Energy and Economic Development;
- ChevronTexaco Corporation;

SECARB Technical Team and
Technology Coalition Members *(current as of 09/30/05)*

Lead: Southern States Energy Board (SSEB)
Advanced Resources, International
AGL Resources
American Electric Power
Arkansas Oil and Gas Commission
Augusta Systems, Inc.
BP America
CO_2 Capture Project
Center for Energy and Economic Development
ChevronTexaco Corporation
Clean Energy Systems, Inc.
Composite Technology Corporation
Dominion
Duke Power
Edison Electric Institute
Electric Power Research Institute (EPRI)
Entergy Services
Florida Power & Light Company
Geological Survey of Alabama
Georgia Environmental Facilities Authority
Georgia Forestry Commission
Gulf Coast Carbon Center, University of Texas at Austin
Interstate Oil and Gas Compact Commission
Louisiana Department of Environmental Quality
Marshall Miller & Associates
Massachusetts Institute of Technology (MIT)
Mississippi State University (MSU) Diagnostic Instrumentation and Analysis Laboratory (DIAL)
North American Coal Corporation, The
North Carolina State Energy Office
Nuclear Energy Institute
Oak Ridge National Laboratory
Old Dominion Electric Cooperative
Progress Energy
SCANA Corporation
South Carolina Public Service Authority/Santee Cooper
Southern Company
Tampa Electric Company
Tennessee Valley Authority (TVA)
Virginia Center for Coal and Energy Research,
Virginia Polytechnic Institute and State University
Winrock International

- Clean Energy Systems, Inc.;
- Composite Technology Corporation;
- Dominion;
- Duke Power;
- Edison Electric Institute;
- Entergy Services;
- Florida Power & Light Company;
- Georgia Environmental Facilities Authority;
- Georgia Forestry Commission;
- Interstate Oil and Gas Compact Commission;
- Louisiana Department of Environmental Quality;
- Marshall Miller & Associates;
- North American Coal Corporation, The;
- North Carolina State Energy Office;
- Nuclear Energy Institute;
- Oak Ridge National Laboratory;
- Old Dominion Electric Cooperative;
- Progress Energy;
- SCANA Corporation;
- South Carolina Public Service Authority/Santee Cooper;
- Southern Company; and
- Tampa Electric Company.

The list of Technology Coalition partners has increased from 18 organizations when first published on December 31, 2003, to 31 when last published (as Phase I) on September 30, 2005 (Deliverables Appendix Document, Volume II, Bookmark 1.C).

Task 2: Characterize the Region

The SECARB region has been characterized relative to sources, sinks, transport, sequestration options, and existing and future infrastructure requirements. Information gathered by SECARB partners during Phase I characterization has been documented in topical reports as listed below. Key information has been archived in a relational database and made available in GIS format.

2.A. Preliminary assessment of CO2 sources in the region, promising geologic formations, and promising terrestrial sinks within the region. The information gathered for the preliminary assessment of CO2 sources in the region is summarized in a final topical report by Massachusetts Institute of Technology (Deliverables Appendix Document, Volume II, Bookmark 2.A1). Promising geologic formations for the region have been summarized in a final topical report by Augusta Systems, (Deliverables Appendix Document, Volume I, Bookmark 2.A2). Promising terrestrial sinks within the original nine-state SECARB region have been identified by Winrock International in a final topical report (Deliverables Appendix Document, Volume I, Bookmark 2.A3). Supplemental information on promising terrestrial sinks has been provided in topical reports by the University of Texas for Texas (Deliverables Appendix Document, Volume II, Bookmark 2.A4) and Virginia State University and Polytechnical Institute for the Commonwealth of Virginia (Deliverables Appendix Document, Volume II, Bookmark 2.A5).

2.B. Preliminary assessment of transport mechanisms and existing infrastructure. This assessment matched sources and sinks and addressed transportation issues that would be associated with key pairings. The final topical report by Massachusetts Institute of Technology (Deliverables Appendix Document, Volume II, Bookmark 2.B) identifies existing CO2 infrastructure and assesses transport mechanisms. The report utilizes the eastern counties of Texas as a prototype for matching sources and sinks and evaluating the comparative costs of transporting CO2 from identified sources to potential geologic sinks.

2.C. Summary of existing separation/purification capabilities and existing commercial users. This summary, prepared by Mississippi State University (Deliverables Appendix Document, Volume I, Bookmark 2.C) highlighted a limited regional capability for separation and purification of CO2. Existing commercial users in the region are generally limited and often require food-grade or high purity industrial CO2.

2.D. Summary of data gaps and assessment of the reasonableness of filling the gaps. ***(NOTE: To be developed by SSEB for submittal on August 31, 2006 with Final Report)***

2.E. Relational database and GIS archive of characterization data. SECARB has utilized relational databases and GIS-compatible data systems, as noted in its report “SECARB Database/Characterization Data” (Deliverables Appendix Document, Volume I, Bookmark 2.E), to the extent possible, in order to conduct regional analyses to identify potential options for both capture/storage and sink enhancement.

Task 2 Highlights

During Phase I, the SECARB team identified many possible terrestrial lands and geologic formations that could be used to sequester carbon dioxide. The challenge was not one of lacking prospects for terrestrial or geologic sequestration, but to determine which locations and techniques would be best. Therefore, to properly prioritize the sinks, it was necessary to build upon the characterization of the region with respect to where the sinks were generally located and then to focus on areas that appeared to have the best overall potential considering both sources and sinks as well as the quantity and quality of available information.

The Massachusetts Institute of Technology continues to receive data and verify it locally. Source data on the MIT server has been linked to the DOE National Carbon Database (NATCARB), a national database covering all regional carbon sequestration partnerships.

Regional Sources

A CO_2 source database was created for the SECARB GIS analyses. The database contains the location and capacities of the major stationary sources of CO_2 in the SECARB study area. It also includes annual CO_2 emissions. CO_2 emissions from power plants were obtained from the US Environmental Protection Agency (USEPA) eGRID database. For other CO_2 sources, the emissions were estimated using emissions factors based on annual production.

The source database contains the following eight major stationary source categories:

- Power plants
- Ammonia plants
- Cement plants
- Ethylene plants
- Ethylene oxide plants
- Gas processing facilities
- Iron & steel plants
- Refineries

Facility Data Sources

The USEPA eGRID database was used exclusively for the power plant data cited within the SECARB study. For other major CO_2 sources, the ECOFYS database developed for the IEA GHG program was used as an initial starting point. Records within the ECOFYS database were then upgraded using the sources listed in Table 1. Specifically, new data sources were used for ammonia plants, cement plants and refineries. Updated data was also used for gas processing facilities. No changes were made to the data sources for ethylene, ethylene oxide, and iron and steel plants because the ECOFYS database already contained the most recent and accurate datasets available for these sources. See Table 1 for details on the data sources used for each emissions source category.

Table 1. Data Sources

Category	Data Source	Details
Power plants	US Environmental Protection Agency (USEPA) eGRID Database (2002) http://www.epa.gov/cleanenergy/egrid/index.htm	- Best data source identified - Plants located - CO2 emissions estimated - Database to be updated when 2004 data released
Ammonia plants	International Fertilizer Development Center Report "North America Fertilizer Capacity" (October, 2004) http://www.ifdc.org/New_Design/Publications/Market_Reports/index.html	- Best data source identified - Plants located - Plant capacities estimated
Cement plants	"U.S. and Canadian Portland Cement Industry: Plant Information Summary," Portland Cement Association, 2002. http://www.cement.org/bookstore/	- Best data source identified - Plants located - Plant capacities estimated
Gas processing facilities	Oil and Gas Journal Worldwide Gas Processing Survey (2003) http://orc.pennnet.com/surveys/aboutsurveys.cfm USGS Organic Geochemistry Database http://energy.cr.usgs.gov/prov/og/ (well CO2 levels)	- Best data sources identified for gas processing capacity and well CO_2 levels - Processing capacities of plants estimated
Refineries	US Department of Energy – Energy Information Administration (2004) http://www.eia.doe.gov/oil_gas/petroleum/data_publications/refinery_capacity_data/refcapacity.html	- Best data source identified - Plants located - Plant capacities estimated
Ethylene plants	From Ecofys: *Ethylene Report*, Oil & Gas Journal, April 23, 2001	- Best data source identified - Plants located - Plant capacities estimated
Ethylene oxide plants	From Ecofys: ChemWeek Website; http://www.chemweek.com, 2001	- Best data source identified - Plants located - Plant capacities estimated
Iron and steel plants	From Ecofys: *World Steelworks Survey*, SteelEye, 2001	- Best data source identified - Plants located - Plant capacities estimated

The eGRID and ECOFYS databases contain geographic coordinate information for the vast majority of the stationary CO_2 emissions sources in the SECARB region. In cases where this data was unavailable, the USGS Geographical Names Information System database (GNIS) was used to lookup the missing data.

CO_2 Emission Factors

Except for the eGRID database, the data sources in Table 1 provide production capacity numbers but do not have information on CO_2 emission rates. In order to convert these capacity numbers to CO_2 emission rates, emission factors for each of the source categories were identified. These are outlined in Table 2.

It is important to note that the CO_2 emissions estimated from applying these emission factors are very approximate. They are useful for comparing the total emissions from each source type, but may not be an accurate estimate of emissions from any individual source.

Table 2. CO_2 Emission Factors

Category	Emission Factor	Units	Source
Power	n/a	n/a	CO_2 emissions explicitly given in eGRID database
Ammonia	1.13	kg CO_2/kg Ammonia	International Fertilizer Development Center (IFDC)
Cement	0.75	kg CO_2/kg Clinker	Hanle, "CO_2 Emissions Profile of the US Cement Industry," US EPA, 2004
Gas Processing	608	tCO_2/mmcfd/yr	ECOFYS, based on 4% average inlet gas CO_2 concentration
Refineries	9.9	tCO2/BPD/yr	ExxonMobil "Report on Energy Trends, Greenhouse Gas Emissions and Alternative Energy," 2004 - Calculated as the company-wide average refinery emission rate
Ethylene	2.43	kg CO_2/kg Ethylene	ECOFYS
Ethylene Oxide	0.51	kg CO_2/kg Ethylene Oxide	ECOFYS
Iron and Steel	0.1468	Kg CO_2/kg Steel	US EPA, "Direct Emissions from Iron and Steel Production," 2002

Power Plants

The database used 2002 USEPA eGRID data for power plant capacities, locations, operating factors, and CO_2 emission rates. The database only contains fossil power plants that are fired by coal, oil, or gas. The CO_2 emissions for these power plants were directly reported in the eGRID data and no emission factors were used to calculate total emissions.

The USEPA eGRID database is the best available database of power plant emissions information. The database is updated and re-released on a periodic basis. The analyses within this report are based on the most recent version of the database available during Phase I study. The database was released in May 2003 and contains updated data from the year 2000. Table 3 summarizes the fossil power plants in the study area by state. Figure 1 shows the geographical distribution and the CO_2 emissions for fossil power plants in the SECARB region.

Table 3. Power Generation Capacity and CO_2 Emissions by Fuel and State (2000)

	Gas			Oil			Coal		
State	Number	Capacity (MW)	CO_2 Emissions (Mt)	Number	Capacity (MW)	CO_2 Emissions (Mt)	Number	Capacity (MW)	CO_2 Emissions (Mt)
AL	15	1,030	1.9	0	0	0	10	14,904	88
AR	12	2,637	3.4	1	8	0	3	3,911	29
FL	42	10,045	12.4	23	15,218	31.4	13	12,732	74
GA	19	4,501	2	25	1,205	1.1	16	15,804	84
LA	54	14,795	31.1	0	0	0	4	3,360	18
MS	22	4,621	6.6	3	807	2.5	4	2,498	16
NC	7	3,747	1.2	12	118	0	29	14,548	78
SC	8	2,029	0.5	3	246	0	14	7,637	41
TN	5	1,132	0.3	0	0	0	13	12,990	65
TX*	126	47,793	89.6	1	11	0	17	19,197	143
VA	12	3,781	1.6	13	435	0.1	21	6,855	37
Total	322	96,110	151	81	18,048	35	144	114,435	671

* eastern Texas

Figure 1. Fossil-Fired Power Plants

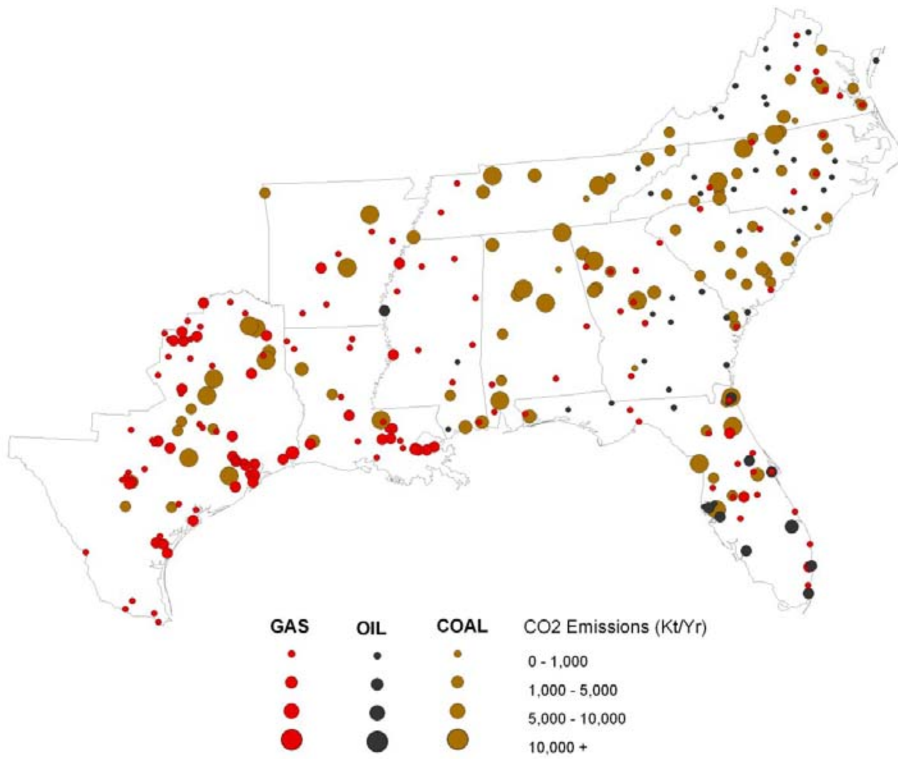
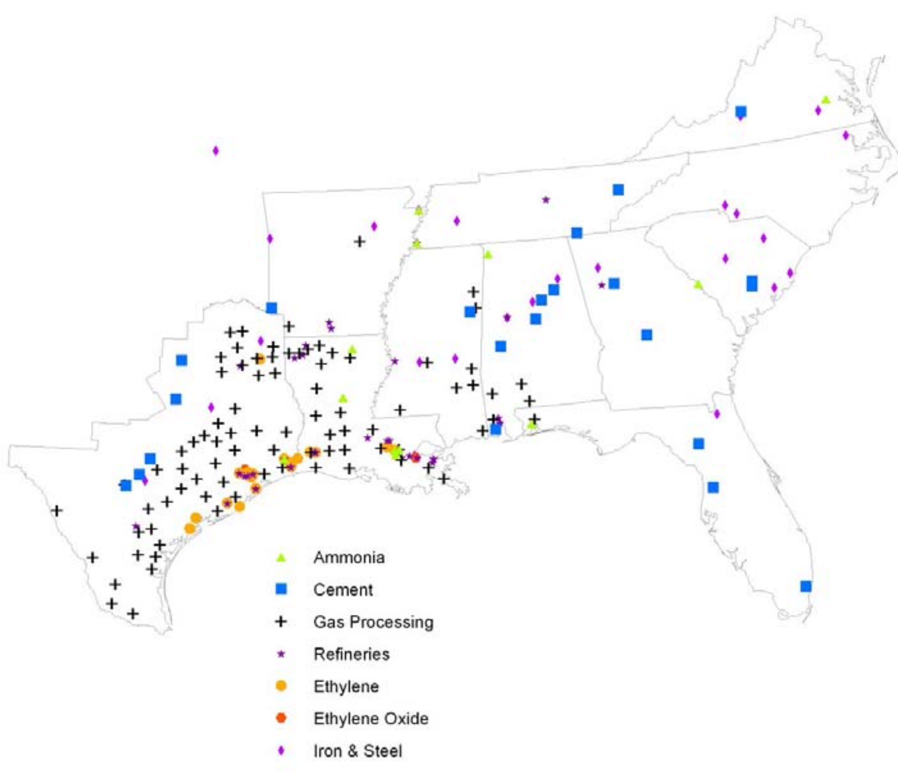


Figure 2. Non-Power Stationary CO_2 Sources



Non-Power Stationary CO_2 Sources

The SECARB region also hosts a variety of non-power stationary CO_2 sources. Figure 2 shows the geographical distribution of the non-power stationary CO_2 sources included in the database. The following section briefly summarizes each type of these non-power stationary CO_2 sources in the database.

Ammonia Plants

The ammonia plant database was updated with the latest available numbers from the International Fertilizer Development Commission (IFDC). The most recent numbers were released in October 2004. This database was cross-referenced with the ECOFYS database to determine the locations of facilities. In addition, the USGS GNIS database was used to locate facilities not included in the ECOFYS database. Table 4 summarizes the ammonia facilities in the study area by state.

Table 4. Ammonia Plant Capacity and Estimated CO_2 Emissions by State

State	Number	Capacity (kt/yr)	Estimated CO_2 Emissions (kt/yr)
AL	1	193	218
AR	1	467	527
FL	1	86	97
GA	1	758	856
LA	8	5,605	6,334
MS	0	0	0
NC	0	0	0
SC	0	0	0
TN	1	409	462
TX*	1	255	288
VA	1	584	660
Total	15	8,357	9,443

* eastern Texas

Cement Plants

The cement plant database was revised with new data from the Portland Cement Industry Association. The most recent database (December 2001) was used. This database was cross-referenced with the ECOFYS database to determine the locations of facilities. In addition, the USGS GNIS database was used to locate facilities not included in the ECOFYS database. Table 5 summarizes the cement production facilities in the study area by state.

Table 5. Cement Plant Capacity and Estimated CO_2 Emissions by State

State	Number	Capacity (kt/yr)	Estimated CO_2 Emissions(kt/yr)
AL	5	5,308	3,981
AR	1	803	602

FL	4	3,158	2,369
GA	2	1,355	1,016
LA	0	0	0
MS	1	419	314
NC	0	0	0
SC	3	2,725	2,044
TN	2	1,436	1,077
TX*	9	9,917	7,438
VA	1	1,120	840
Total	28	26,241	19,681

* eastern Texas

Refineries

The online database of the Energy Information Agency (EIA) of the US Department of Energy (DOE) was used to revise capacity estimates of refineries in the study area. The ECOFYS database was used for plant locations, with the USGS GNIS used to verify and update the location of new facilities. Table 6 summarizes the refineries in the study area by state.

Table 6. Refinery Capacity and Estimated CO_2 Emissions by State

State	Number	Capacity (1000 barrels / stream day)	Estimated CO_2 Emissions(kt/yr)
AL	3	130	1,289
AR	2	97	955
FL	0	0	0
GA	1	34	332
LA	16	2,452	24,275
MS	1	227	2,242
NC	0	0	0
SC	0	0	0
TN	1	120	1,188
TX*	16	3,002	29,719
VA	1	250	2,475
Total	41	6,311	62,475

* eastern Texas

Gas Processing Facilities

The database for gas processing facilities used data from the 2003 Oil and Gas Journal Gas Processing survey. This database was cross-referenced with the ECOFYS database to determine the locations of facilities. In addition, the USGS GNIS database was used to locate facilities not included in the ECOFYS database. Table 7 summarizes the gas processing facilities in the study area by state. The estimated CO_2 emissions in Table 7 are calculated using the CO_2 emission factor given in Table 2.

Table 7. Gas Processing Capacity and Estimated CO_2 Emissions by State

State	Number	Capacity (MMCFD)	Estimated CO_2 Emissions(kt/yr)
AL	9	766	466
AR	2	872	531
FL	1	90	55
GA	0	0	0
LA	47	10,015	6,092
MS	9	1,876	1,141
NC	0	0	0
SC	0	0	0
TN	0	0	0
TX*	96	12,455	7,577
VA	0	0	0
Total	164	26,074	15,862

* eastern Texas

However, the CO_2 emission rate from gas processing facilities is highly dependent on the percentage of CO_2 in the gas being processed by each facility. Initial analysis indicates that gas processing facilities in the SECARB region are likely to emit less CO_2 than is estimated in this study using the ECOFYS emissions factor. In order to better estimate these emissions, the USGS organic geochemistry database has been obtained. This database contains the CO_2 concentrations of the gas wells in the study area. Phase II analyses will provide better CO_2 emissions estimates for the gas processing facilities by revising the CO_2 emissions factors using the USGS organic geochemistry database.

Ethylene, Ethylene Oxide, and Iron and Steel Plants

The ECOFYS database contained the most detailed and up to date datasets for ethylene, ethylene oxide, and iron and steel plants. ECOFYS used the ethylene information from the Oil & Gas Journal's *Ethylene Report* (April 2001), the ethylene oxide information from the ChemWeek (www.chemweek.com), and the iron and steel information from the 2001 *World Steelworks Survey*. The information from these publications was not supplemented with any additional sources. Table 8 summarizes the plant capacity and the estimated CO_2 emissions for these three types of non-power CO_2 sources by states.

Table 8. Ethylene, Ethylene Oxide, and Iron and Steel Plants Capacity and Emissions Estimate by State

State	Iron and Steel			Ethylene			Ethylene Oxide		
	Number	Capacity (kt/yr)	CO_2 Emissions (kt/yr)	Number	Capacity (kt/yr)	CO_2 Emissions (kt/yr)	Number	Capacity (kt/yr)	CO_2 Emissions (kt/yr)
AL	5	3,739	549	0	0	0	0	0	0
AR	4	2,115	310	0	0	0	0	0	0
FL	1	356	52	0	0	0	0	0	0

GA	1	712	105	0	0	0	0	0	0
LA	1	712	105	5	3,547	8,619	4	1,730	882
MS	2	401	59	0	0	0	0	0	0
NC	3	890	131	0	0	0	0	0	0
SC	4	2,992	439	0	0	0	0	0	0
TN	3	1,602	235	0	0	0	0	0	0
TX*	6	2,271	333	19	16,870	40,994	7	2,255	1,150
VA	2	1,647	242	0	0	0	0	0	0
Total	32	17,437	2,560	24	20,417	49,613	11	3,985	2,032

* eastern Texas

Regional Sinks

Terrestrial Sequestration

Terrestrial carbon sequestration options are defined as land-resource management actions that have the potential to increase carbon storage, relative to a baseline of unchanging management. The Winrock analyses for the SECARB states incorporate both spatial (e.g., STATSGO soils maps and 30 m resolution remote sensing classified maps) and tabular data (e.g. Forest Inventory and Analysis data base on forest volume, agricultural statistics). The study team obtained information about current land use (based on 1992 NLCD), potential changes in land use and the incremental carbon resulting from the change, opportunity costs, conversion costs, annual maintenance costs, and measurement and monitoring costs. The analyses are performed in a geographic information system (GIS) to include the diversity of land uses, rates of carbon sequestration, and costs in the analyses. In general, this approach identifies and locates classes of land where there is potential to change the use to a higher carbon content, estimate rates of carbon accumulation for each major potential land-use change activity for each land class, assigns values to each contributing cost factor, identifies datasets and methods to estimate project risks, and identifies datasets and methods to estimate co-benefits.

The methods used were first developed by Winrock International for an Electric Power Research Institute (EPRI) project “Quantifying Carbon Market Opportunities in the United States” completed in 2005. The methods were modified to include more conservative assumptions for growth and yield potential for various trees and regional estimates for opportunity costs rather than county-level estimates.

The lands are classified into four main groups: crop lands, grazing lands (including improved and unimproved pastures), forests, and other (Table 9). Cropland is designated as small grains and row crops; grazing lands are designated pasture/hay; and forests include deciduous, evergreen, mixed, wooded wetlands, and transitional forest.

Table 9. Area of Land Cover Classes in SECARB States

Land Cover	Area	
	Hectares	Acres
Grazing	11,344,749	28,033,485
Agriculture	17,178,780	42,449,690
Forest	70,627,008	174,523,137
Other	13,394,934	33,099,602
Total	112,545,471	278,105,914

Terrestrial Carbon Sequestration Potential

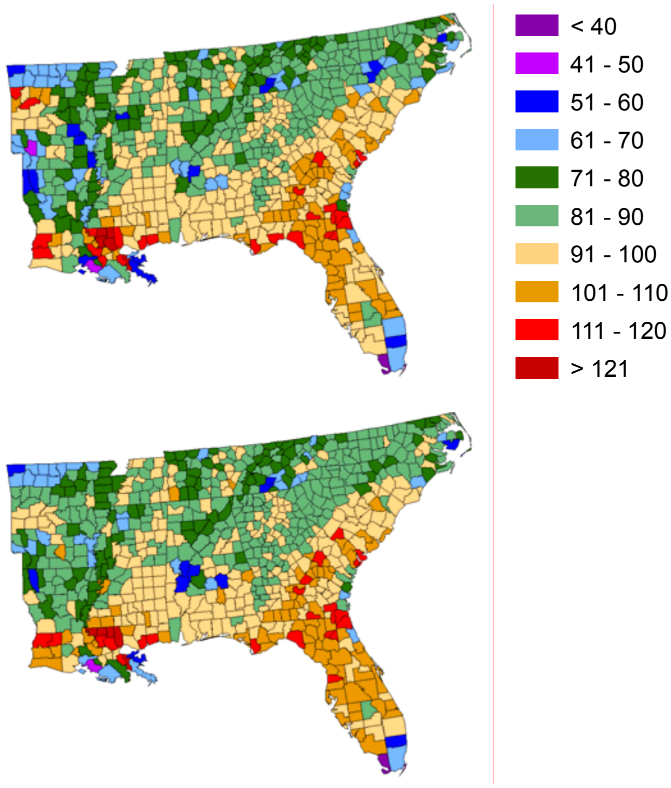
Table 10 summarizes the projected amount of carbon within the nine state region that comprised Winrock's scope of work. Texas and Virginia reports are discussed later in this section. In general, longer time periods produce more carbon at lower costs but landowners may be more hesitant to commit land for longer time periods. Due to the lower opportunity costs associated with grazing, afforestation of grazing lands provides the most carbon at the least cost. Using a price point of \$10/t CO_2 (\$37/t C), approximately 60% of grazing land but only 6% of cropland could be afforested for a 20 year period and almost all grazing land would be available for 80 years of afforestation but only 20% of cropland.

Table 10. Summary of the quantity of carbon (million tons CO_2) and area (million acres) available at selected price points on existing agricultural lands after 20, 40, and 80 years

Activity	Quantity of C—million metric tons CO_2			Area available—million acres		
	20 years	40 years	80 years	20 years	40 years	80 years
Crop lands—Afforestation						
≤\$10/metric tons CO_2	203	308	388	2.3	7.7	7.9
≤\$15/metric tons CO_2	1,612	3,880	4,786	19.3	28	28.6
Grazing lands—Afforestation						
≤\$10/metric tons CO_2	1,379	3,277	4,310	16	24.4	26.9
≤\$15/metric tons CO_2	1,735	3,469	4,353	22	27	27.3

After 40 years, the amount of carbon sequestered per unit area on crop and grazing lands varies from as little as 40 t/ ha (16 t/acre) to as much as 120 t/ha or more (about 50 t/acre) in southern counties.

Figure 3. Spatial representation, at the county scale of resolution, of the projected area-weighted county average quantity of carbon per ha (t C/ha) sequestered through afforestation of crop lands (top graphic) and grazing lands (bottom graphic) for 40 year time period.



Projected carbon accumulation potential is dependent on the projected forest types and site characteristics, with areas of poor site conditions accumulating lower levels of carbon. Unit cost in $ per ton carbon are dependent on both the carbon sequestration potential and total costs associated with conversion through afforestation. It is clear that the costs are lower for grazing lands than for croplands, and lower the longer the trees are allowed to grow (Figure 4) Opportunity costs of conversion of cropland are greater than those of grazing land, thus grazing lands have the lowest $/t carbon associated with them. Some of the highest cost carbon is in Florida and Louisiana caused by the high opportunity cost associated with sugar production in Florida and rice in Louisiana.

The largest quantities of carbon that could be sequestered are in counties along the Mississippi Valley, particularly in Louisiana (Figure 5), but these counties also contain some of the more expensive carbon (Figure 4). Comparing the map of quantity with the map of costs suggest that afforestation of croplands and grazing lands in Arkansas offer some of the most cost–effective carbon opportunities.

Although forests cover 63% of the land area in SECARB states, the cost of carbon sequestration from changing forest management practices is high and produces lower C quantities than afforesting agricultural lands. Lengthening rotations in industrial softwood forests is relatively expensive compared to afforestation. For all states in the region, 7.0 million tons C (28 million short tons CO_2) could be produced at a price of less than $ 100/t C ($25/short t CO_2).

Figure 4. Spatial representation, at the county scale of resolution, of the cost to sequester carbon ($/t C; divide by 4 to convert to $/short t CO2) through afforestation of (a) crop lands and (b) grazing lands for 20, 40, and 80 year time periods.

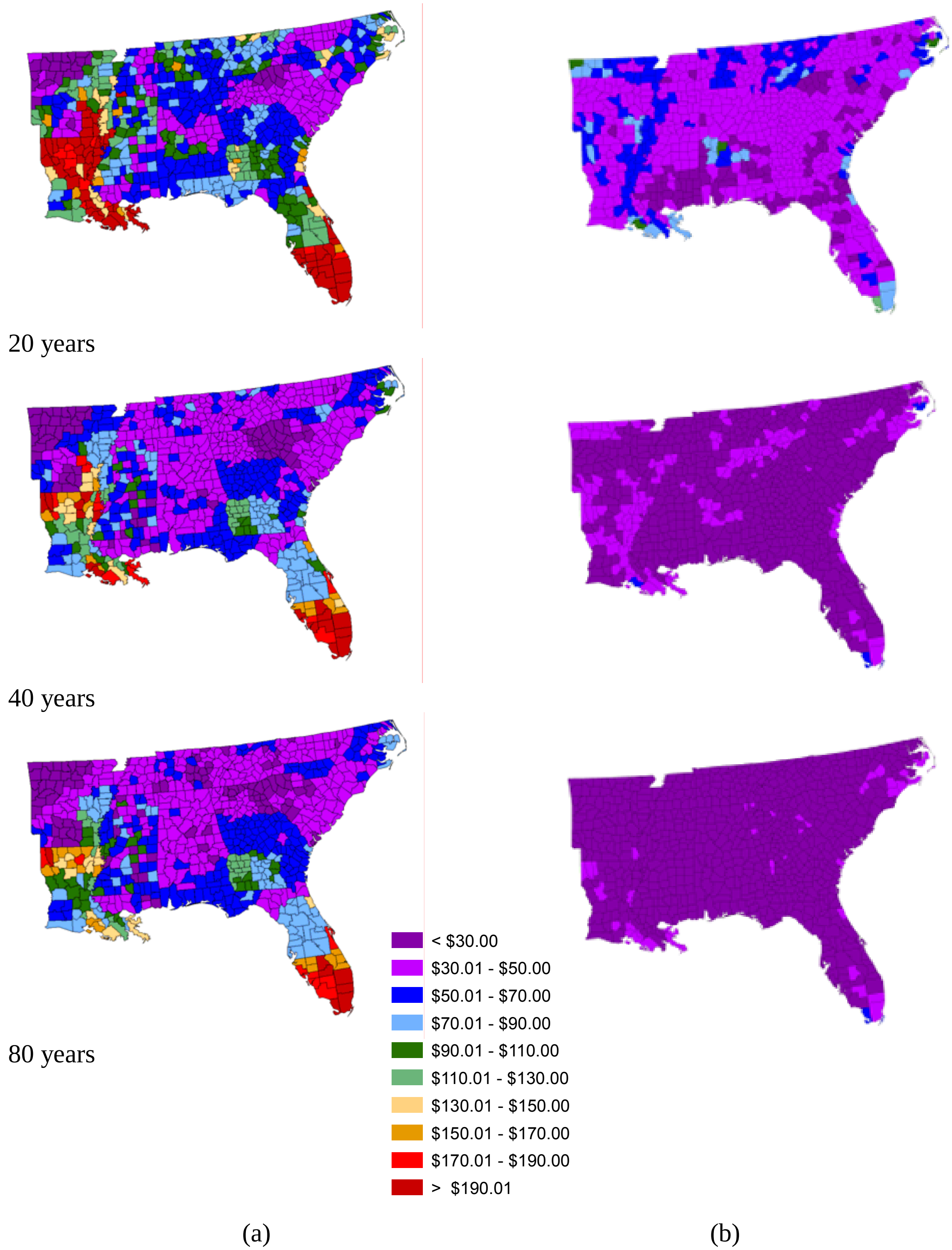
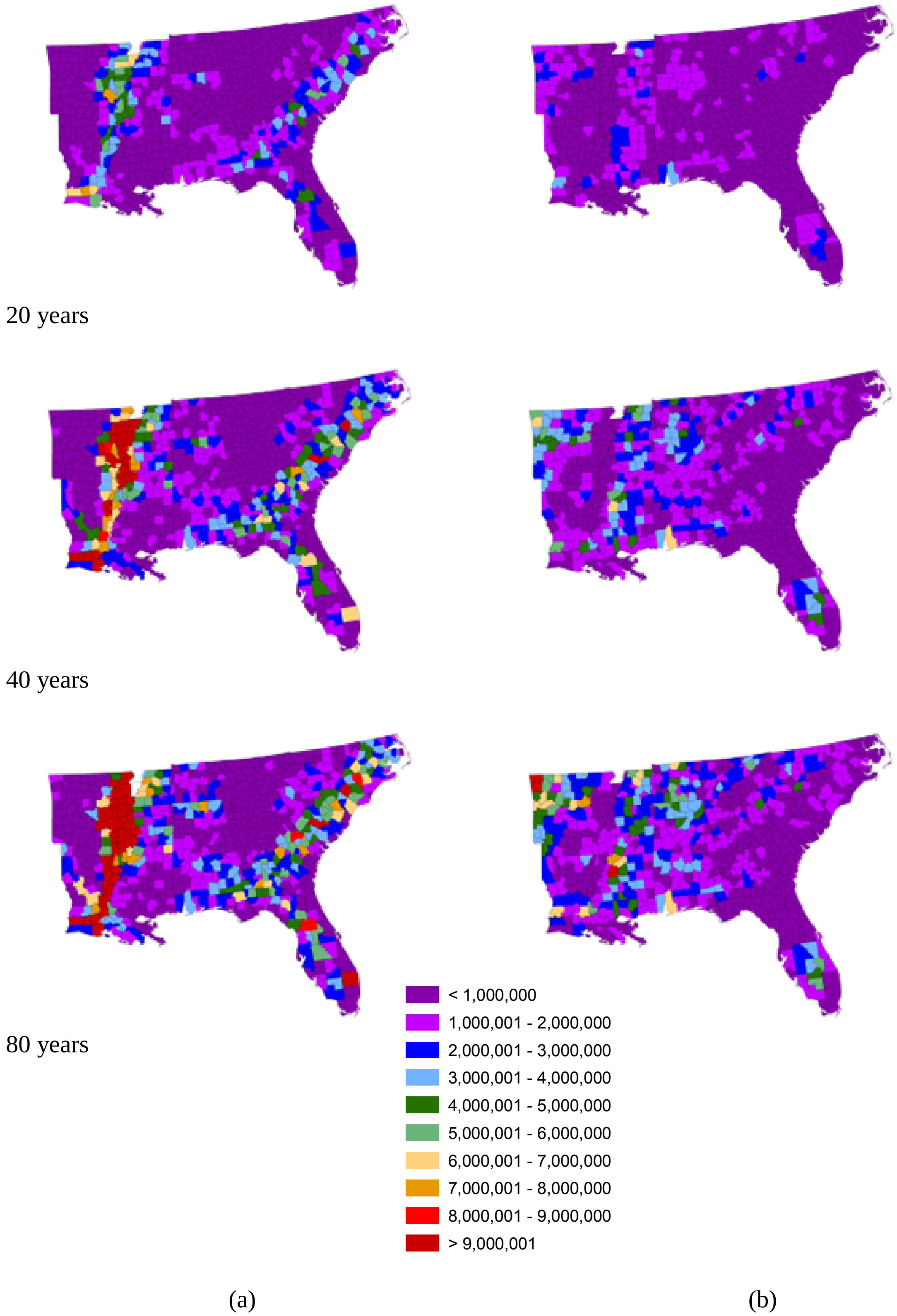


Figure 5. Distribution at the county scale of the total quantity of carbon sequestered, in metric tons, through afforestation of (a) crop lands and (b) grazing lands over the 20, 40, and 80 year time periods.



Terrestrial Carbon Sequestration Options – Texas

During Phase I, the University of Texas provided information on the potential for terrestrial carbon sequestration options to offset carbon emissions from energy production within the state of Texas. To assess the potential for carbon sequestration in Texas, a baseline analysis of past land-use practices was assembled. Changes in land use are documented and the baseline is set as land use prior to year 1990. Once past land-use practices were established, future changes in land use were documented and presented in the context of past practices, and the impact on carbon storage was assessed.

The 1992 National Land Cover Data (NLCD) in Figure 6 serves as the baseline land use for Texas. As indicated in Table 11, approximately 50% of the state is rangeland, most of which occurs in Railroad Commission of Texas Districts 7c and 8A. Although forests comprise only 15% of the state's land use, most occur in the east half of the state, with percentages of up to 54 percent in District 6. Agricultural areas are widespread throughout the state, with the exception of west Texas (Districts 7c and 8).

Data sources used to provide baseline information include NLCD, and National Agricultural Statistics Service (NASS) county-level tabular databases. National Resources Inventory data are collected by the National Resources Conservation Service (NRCS). Information on land classifications is available on NRI online at http://www.statlab.iastate.edu/survey/nri/est971nr.pdf. Information from the Farmland Mapping and Monitoring Program (FMMP) will also be collated. Full metadata, data collection details, and class descriptions are available online at ftp://ftp.consrv.ca.gov/pub/dlrp/FMMP/fmmp_meta.txt.

Figure 6. Railroad Commission of Texas district boundaries and National Land Cover Database (NLCD, 1992) land use/land cover.

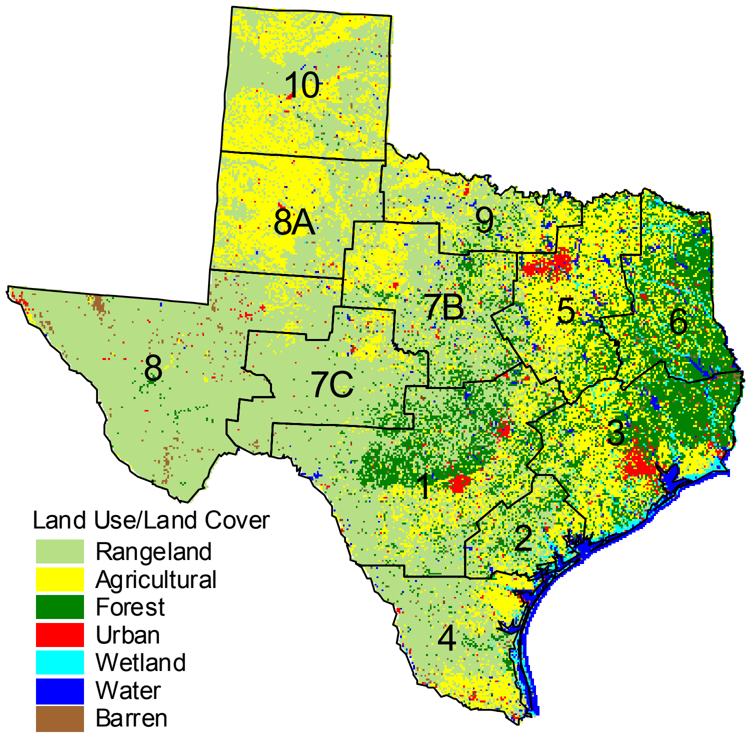


Table 11. Calculated land use for regions of Texas divided by RRC districts.

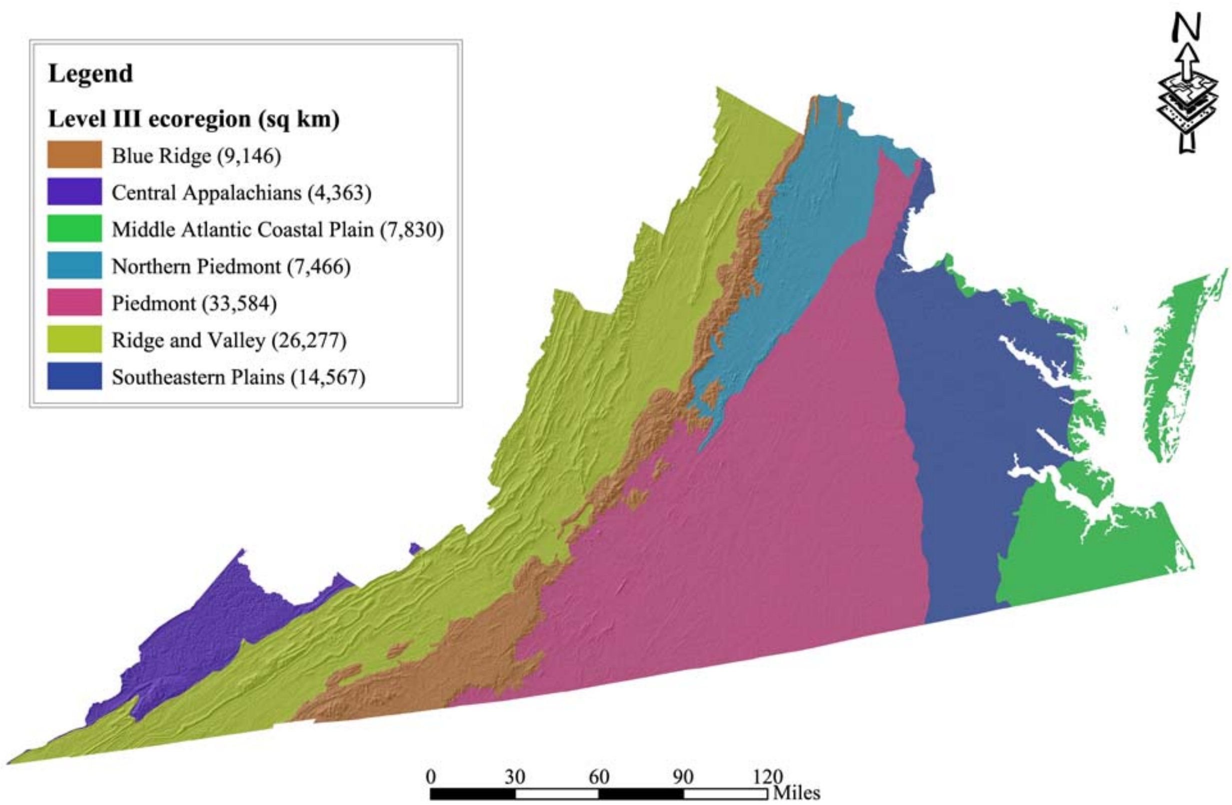
	Land-Use Category Areas (%)						
District	*Rangeland*	*Agricultural*	*Forest*	*Urban*	*Wetland*	*Water*	*Barren*
1	55.9	15.6	24.6	2.2	0.1	1.0	0.6
2	42.4	28.0	20.6	1.1	4.7	2.8	0.4
3	5.4	35.6	40.1	5.7	8.3	3.1	1.7
4	63.0	24.2	5.4	1.7	2.0	2.1	1.7
5	10.0	56.1	21.3	5.8	2.5	3.8	0.4
6	0.1	30.7	54.1	1.8	8.0	3.5	1.8
7B	61.1	24.1	11.7	1.1	0.1	1.3	0.6
7C	85.9	8.0	4.3	0.5	0.0	0.4	0.9
8	92.7	3.0	0.7	0.7	0.0	0.1	2.8
8A	46.9	51.4	0.1	0.6	0.0	0.3	0.7
9	47.4	38.2	9.2	1.5	0.3	3.0	0.4
10	56.6	41.7	0.2	0.5	0.1	0.3	0.6
Texas	51.3	27.0	15.2	2.0	1.8	1.5	1.2

Rangeland: shrublands and grasslands
Agricultural: row crops, small grains, fallow, pasture/hay, orchards
Forest: perennial, evergreen, mixed
Urban: low- and high-density residential, transportation/industrial, urban grasses
Wetland: herbaceous and woody emergent wetlands
Water: open water
Barren: bare rock, quarries/open pit mines, transitional

Terrestrial Carbon Sequestration Options – Virginia

During Phase I, Virginia Tech analyzed the potential for terrestrial carbon sequestration options to offset carbon emissions from energy production within the Commonwealth of Virginia. Using a Geographic Information System approach, three options were evaluated by applying two modeling methods. The terrestrial carbon sequestration options evaluated are conversion of marginal agricultural land to long-term forest cover, conversion of tillage practices for row crops, and afforestation of agricultural lands within riparian zones and farmed wetlands; each was evaluated on a statewide basis and within each of the state's 7 Level III ecoregions (Figure 7).

Figure 7. Level III ecoregions of Virginia.



Modeling methods applied were the "Winrock method," which was intended to develop estimates from a basis comparable to that applied by Winrock International over other portions of the SECARB region, and alternative methods developed at Virginia Tech ("VT method") which consider additional factors and local conditions. Publicly available data were gathered to develop a spatial database of relevant variables, and that database was manipulated through a variety of GIS analytical techniques to estimate the carbon sequestration for each option. Because the VT methods are based on a more detailed analysis, conclusions regarding the options' carbon sequestration potentials are drawn from the VT method's application.

Of the options evaluated, afforestation of marginal agricultural lands was found to have the highest carbon sequestration potential, averaging 1.4 Tg C yr^{-1} over the first 20 years if applied on all eligible lands (Table 12). The areas with greatest opportunity for application of this option are the Ridge and Valley ecoregion of western Virginia (steep, shallow soils) and in the Tidewater area in eastern Virginia (wet soils). Sequestration potential estimates for the afforestation options are for biomass carbon only and do not consider soil carbon, but other investigators' findings indicate a likelihood that consideration of soil carbon changes would increase the estimated carbon sequestration potentials of these options. The analysis indicates that widespread implementation of this option within the near-term would be capable of offsetting about three percent of annual energy-related CO_2 emissions, on average, over the following 20 years, with sequestration continuing but at declining rates beyond that initial 20-year time frame.

Considering societal effects as well as estimated carbon sequestration rates, we consider the most promising option to be afforestation of marginal agricultural lands in combination with afforestation of selected riparian agricultural lands and management enhancements on residual agricultural lands. The sequestration potential estimates developed through this research are general estimates and do not include carbon losses or gains associated with harvested products, management activities, or any other source/sink of carbon. The estimates presented here are best regarded as potentials that serve as starting points for regional planning projects.

Table 12. Total annual carbon sequestration potential of three land management options by Virginia ecoregion (short-term).

	Total Carbon Sequestered								
	Option A†		Option B‡		Option C§	Option A† Model 2# (Individual Determinations)			
Level III Ecoregion	Model 1¶	Model 2#	Model 1¶	Model 2#	Model 2#	STATSGO	HEL	Steep	All Model 2# Options
	Tg C yr^{-1}								
Blue Ridge	0.23	0.09	0.00	0.00	0.01	0.01	0.02	0.08	0.099
Central Appalachians	0.04	0.03	0.00	0.00	0.00	0.01	0.02	0.02	0.028
M.A. Coastal Plain	0.00	0.27	0.07	0.04	0.03	0.27	0.00	0.00	0.308
Northern Piedmont	0.18	0.17	0.02	0.00	0.02	0.16	0.01	0.01	0.190
Piedmont	0.36	0.11	0.04	0.01	0.03	0.06	0.03	0.03	0.151
Ridge and Valley	1.21	0.68	0.03	0.01	0.07	0.35	0.15	0.35	0.743
Southeastern Plains	0.04	0.07	0.10	0.03	0.01	0.05	0.01	0.01	0.104
Statewide Potential	**2.07**	**1.42**	**0.27**	**0.09**	**0.17**	**0.90**	**0.25**	**0.51**	**1.62**

†Option A: Afforestation of marginal agricultural land (20 yrs)
‡Option B: Conversion from CT to NT row crops (14 yrs)
§Option C: Afforestation of riparian areas currently in agricultural use (20 yrs)
¶Model 1 = Winrock Method
#Model 2 = VT Method

Geologic Sequestration

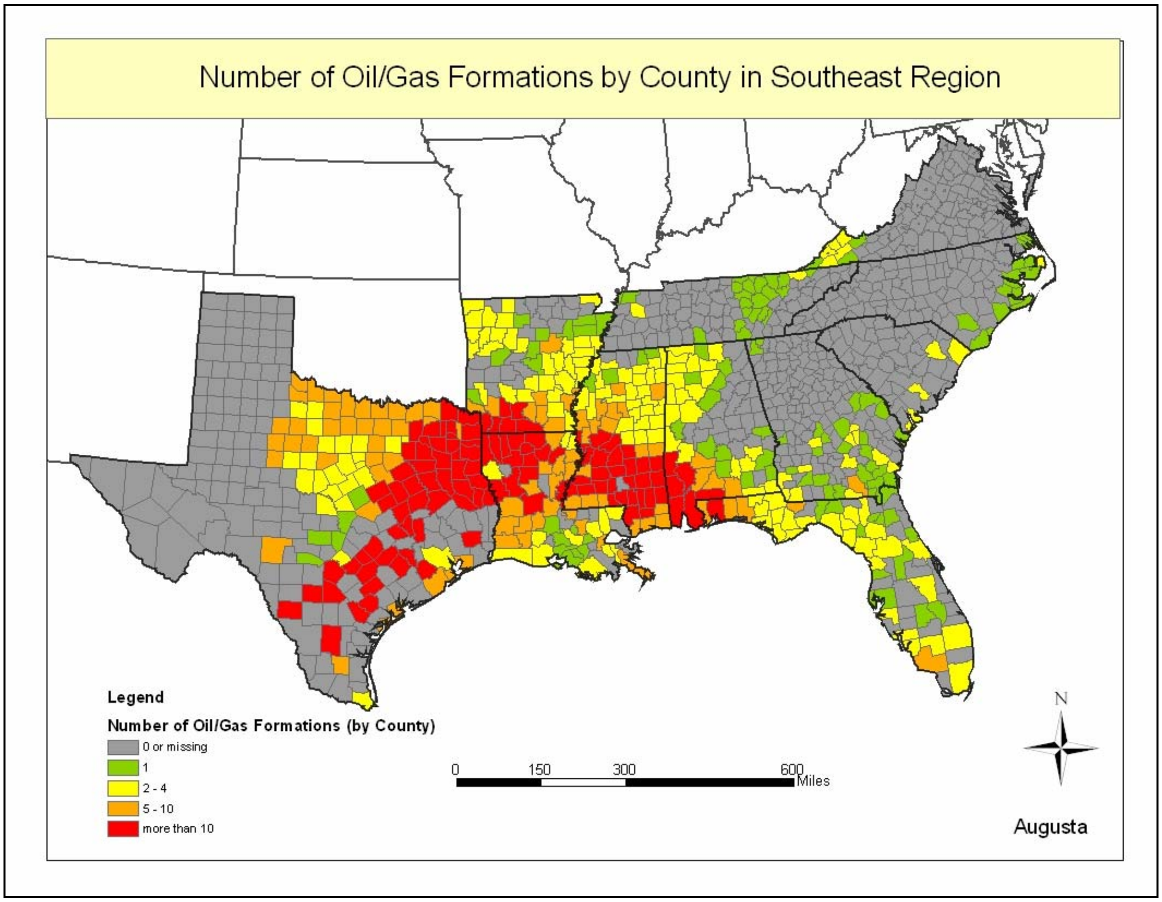
SECARB took a macro-level, dimensional, geographic identification approach to identify areas and particular geologic formations with sequestration potential. Three primary data sets were developed from public data. Each set focused on one of the main types of geologic sinks for sequestration, namely saline formations, coal seams and oil and gas reservoirs. A minimum set of parameters were sought during this step, based at least in part on the information believed to be available. Additional data were collected simultaneously as the opportunity presented itself.

The minimum data sought initially included geographical parameters that would aid in locating the potential sinks (e.g.: state and county names; well location coordinates; oil, gas, or coal field names; formation names; etc.). Technical parameters included formation depth, thickness and porosity as being most essential. Permeability, fluid saturations, pressures, productive areas and area geology were placed at the next level of importance. Of equal importance to geological data were geographical parameters that would aid in locating the potential sinks.

Subsequent steps sought to refine the data from the first step by addressing data availability and quality with respect to potential sequestration targets. The data continued to be gathered, refined and synthesized to compile the most-relevant datasets possible. The data were incorporated into a GIS database for prioritizing field test candidate areas with the best combination(s) of CO_2 sources, sinks and site attributes for constructing a sequestration test facility.

The initial data sets developed for the Southeast region were based on national public data sets that had been developed mainly for reasons other than sequestration, such as oil and gas exploration and production. Logically, it was found that the areas with the most geologic data corresponded with locations that have, historically, been extensively explored for energy and mineral resources. These national data sets, while containing a wealth of information, often contained only a minimum amount of information of direct value to the sequestration effort. The result was a substantial collection of data that could be used for a general characterization of the region but having numerous "holes" or missing data points. This was not unexpected and additional data were sought and obtained from other public and private sources. Figure 8 is a map constructed from the preliminary data indicating large areas in the region with multiple oil or gas producing formations present (indicative of good seals and other favorable geologic conditions), clearly indicating areas that might be more suitable than others for geologic sequestration of CO_2. Primary data sources for the initial phase of geologic characterization included the United States Geological Survey's Assessment of National Oil and Gas Resources publications (1995 and 2001), supplemented by data from DOE’s Gas Information System database (Version 2, 1999), reports from the USGS's National Coal Resource Assessment and publications obtained from the Texas Bureau of Economic Geology. Additionally, detailed information was sought from various state geological surveys and other cognizant state agencies.

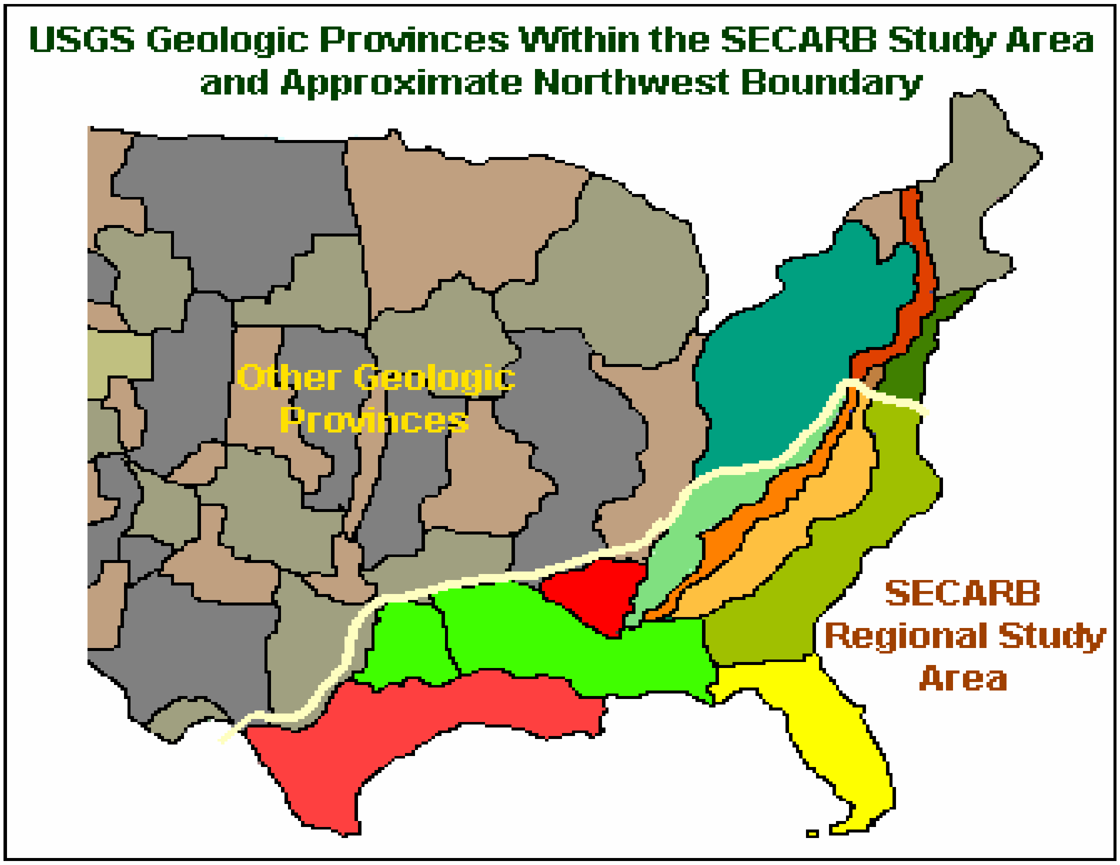
Figure 8. Number of Formations Penetrated by Producing or Exploratory Oil and Gas Wells, By County.



State agencies in five of the 11 SECARB area states participated directly in the SECARB effort: Texas, Louisiana, Mississippi, Alabama, and Virginia. The Florida Panhandle area also is being characterized by the Geological Survey of Alabama. State agencies in North Carolina, South Carolina, Tennessee, Georgia, Arkansas and Florida also were contacted to determine the availability of detailed data from those states. All states were found to be cooperative, but none had digitized information; few had much data on oil, gas, coal and especially salt water aquifers. In every case, the acquisition of information on underground rock formations would require manually searching through paper reports, paper and/or computer spreadsheets and state report forms for information. The agencies were very interested in the project and were willing to cooperate, but did not have extensive electronic data sets nor the resources to compile information for SECARB. They typically recommended that any request for information be as specific as possible so that the correct information could be found quickly.

The USGS publication in 1995 of the “National Assessment of United States Oil and Gas Resources” identified all of the known major geologic oil and gas plays and also identified hypothetical plays where oil and gas reserves were likely to occur, based on known geological characteristics and applied statistics. The geologic regions, provinces and individual stratigraphic plays provide a valuable system for general characterization of the large multi-state SECARB region. The states affiliated with the SECARB partnership are all included in USGS regions six and eight. Figure 9 shows the nine geologic provinces embraced, all or in part, by the characterization study.

Figure 9. Nine Geologic Provinces Considered in the Characterization of the SECARB Region (After USGS).

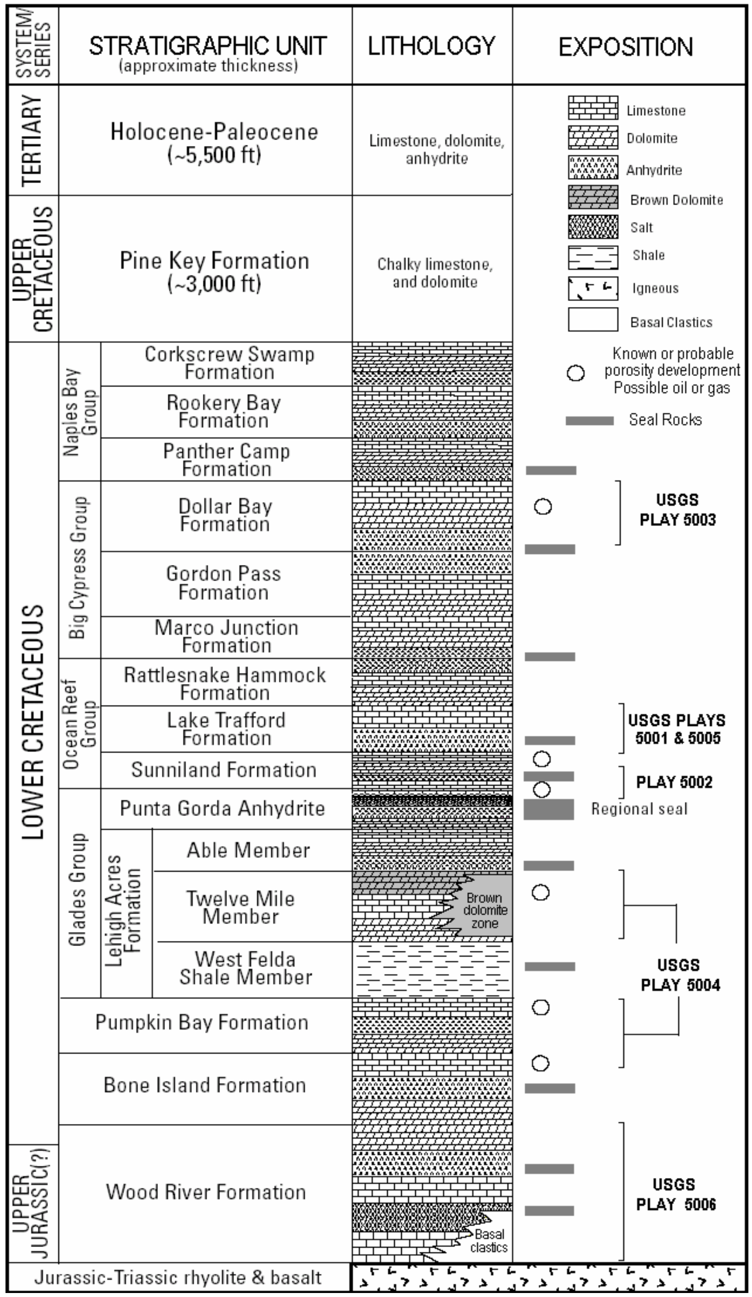


In the northeastern area of the region (Virginia, North Carolina and Tennessee), the primary targets for sequestration will be unmineable coal seams and brine formations. Local opportunities for EOR may be available but will not be the primary targets. Large depleted gas fields and abandoned gas storage fields may also be future options in the northern area. Continued characterization is needed in these areas and, without additional data, the geological suitability of this sub-region is uncertain with respect to carbon sequestration potential.

In the southeastern area of the region (South Carolina, Georgia and Florida), there are minimal opportunities for sequestration as part of the recovery of CBM, oil or gas, so the primary targets will be brine formations. The South Florida basin has a large potential for brine formations, especially in the Lower Cretaceous rocks (see Figure 10) that include the Dollar Bay and Sunniland formations, which also have potential for EOR. The South Florida basin contains a thick column of sediments with porous and permeable zones separated by impermeable anhydrites. Continued characterization is needed in these areas and, without additional data, the geological suitability of this sub-region is uncertain with respect to carbon sequestration potential.

In the central and western parts of the region (Alabama, Mississippi, Louisiana, Texas and Arkansas) sequestration target options include coal, oil, gas and brine formations. The main targets, at least initially, will be oil reservoirs, which are particularly responsive to the injection of CO_2 to enhance oil recovery, with brine formations. The exception to this rule may be in the northern parts of Alabama and Mississippi, where the Black Warrior Basin affords the opportunity for enhanced CBM production from unminable coals.

Figure 10. Stratigraphic section of South Florida Basin highlighting positions of USGS plays (After USGS)



As more is learned about the potential for storage and/or enhanced CBM recovery from the large lignite deposits in the region, those resources may also be utilized in the future for storage of CO_2. Ample opportunities for EOR exist throughout the rest of the area and are more cost-effective than other forms of sequestration. In areas where EOR opportunities are not available, there is a high likelihood of brine formations being available for storing the CO_2.

Even though many "gaps" were found to exist in the publicly-available information, there are enough data to differentiate between areas of good potential for geologic sequestration and areas that may be suitable but pose greater risk of uncertainty. When the areas of good potential were paired with CO_2 sources in the region, it became apparent which potential sink areas could serve as most promising candidates for field verification activities.

Where possible key data on promising locations that was missing from the public data sets was derived from local sources such as oil and gas companies operating in the area or from state geological survey investigation reports performed in the area of interest. GIS maps showing key formations and characteristics to be overlain by CO_2 sources and infrastructure considerations were prepared to assist in the evaluation of potential geologic sequestration options. Upon narrowing the sequestration options to a priority group, these prospects were pursued further to obtain specific information to complete the evaluation of those options. Surviving prospects were evaluated to determine the most promising candidates. The most promising carbon sequestration candidate formations are discussed below.

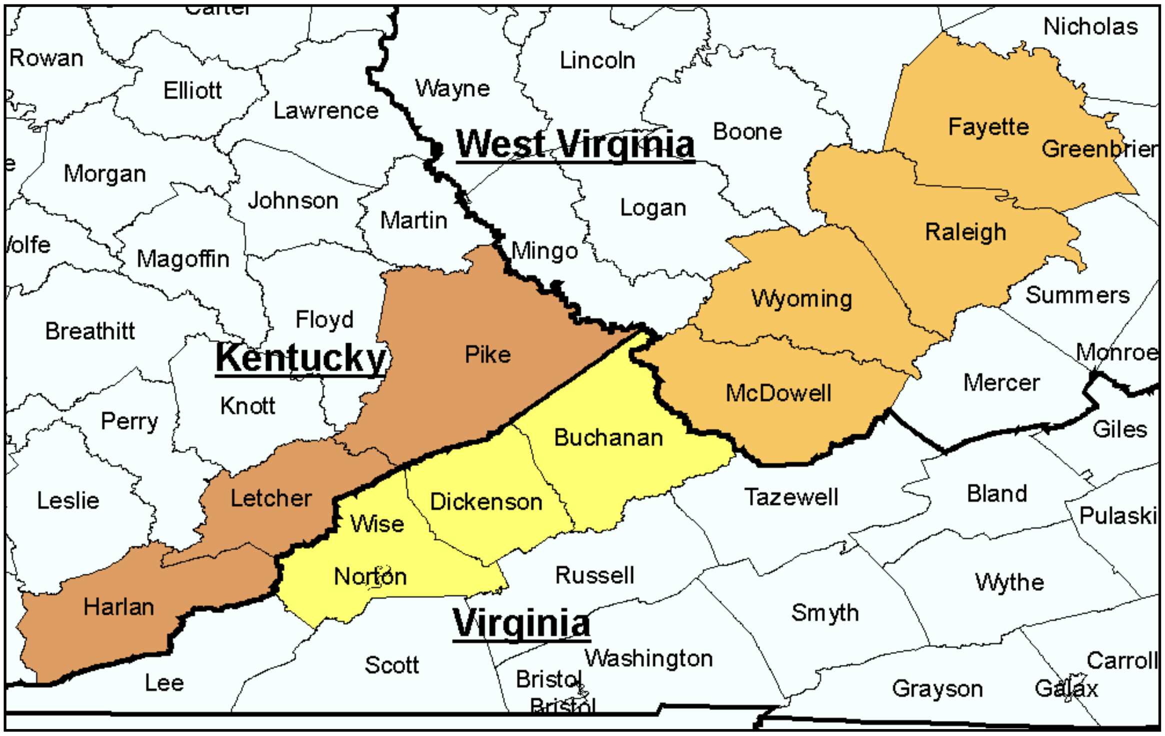
Geological Sequestration - Appalachian Basin Coal Seams

The SECARB region has vast coal reserves and many additional coal resources that may not be economically recoverable (unmineable). Coal seams that are deep (generally below 2400 feet) and that have high gas content may be suitable for utilizing CO_2 to enhance the recovery of coal bed methane and for the long-term storage of $CO_{2.}$

Two areas within the SECARB region currently are being developed for coalbed methane recovery (CBM). One is in the tri-state area of Virginia, West Virginia and Kentucky. The second is in the Black Warrior Basin of Alabama. As a result of the exploration and production activities, extensive data is available in these two specific areas.

Virginia Tech and Marshall Miller and Associates (MMA) have worked to characterize the tri-state CBM area for potential carbon dioxide sinks, sources and transport options. Virginia Tech and MMA developed an approach to gather publicly-available geologic data and to mesh this information with proprietary data, in order to characterize coal seams, oil and gas reservoirs and saline aquifers. Significant progress has been made in identifying and collecting the publicly-available data from the Virginia Division of Gas and Oil and the non-proprietary files of MMA. In order to protect confidentiality, in certain cases, final GIS data will be provided as contour lines without including individual point data.

Figure 11. Carbon Sequestration Focus Areas for Regional Geologic Mapping.



From the detailed level assessment, a list of prospective coal beds for carbon sequestration was developed. The list includes the following seams in the Upper, Middle and Lower Lee formations and the Pocahontas formation:

Upper Lee Formation

- Jawbone
- Tiller
- Upper Seaboard
- Middle Seaboard
- Lower Seaboard

Middle to Lower Lee Formation

- Upper Horsepen
- Middle Horsepen
- C-Seam (P-10)
- War Creek (P-11)
- Lower Horsepen
- X-Seam

Pocahontas Formation

- Pocahontas No. 6
- Pocahontas No. 5
- Pocahontas No. 4
- Pocahontas No. 3

Geologic Sequestration - Black Warrior Basin Coal Seams

The potential for injecting CO_2 into geologic formations to enhance the recovery of oil and coal bed methane is an attractive option. In addition to enhanced hydrocarbon recovery, significant sequestration capacity may exist in saline aquifers. A wide variety of potential geologic sinks exists in the southeastern United States, and these sinks are concentrated in the Black Warrior and Gulf of Mexico basins of Alabama, Mississippi and northwestern Florida.

Accordingly, the Geological Survey of Alabama (GSA) identified and characterized potential geologic sinks in these basins. This work was divided into three tasks. Subtask 2A, Geologic Reservoir Identification and Location, centered on identifying and delineating potential geologic sinks, as well as developing a regional geographic information system that incorporates relevant databases. Subtask 2B, entitled Oil, Gas, and Saline Aquifer Reservoir Property Characterization, focused on the geologic characterization of conventional hydrocarbon reservoirs and deep, saline aquifers that are potential sites for geologic sequestration. Subtask 2C, entitled Coal bed Fluid and Rock Property Assessment, focused on the characterization of mature coal bed methane reservoirs in the Black Warrior basin and on the characterization of potential lignite sinks in the Gulf of Mexico basin.

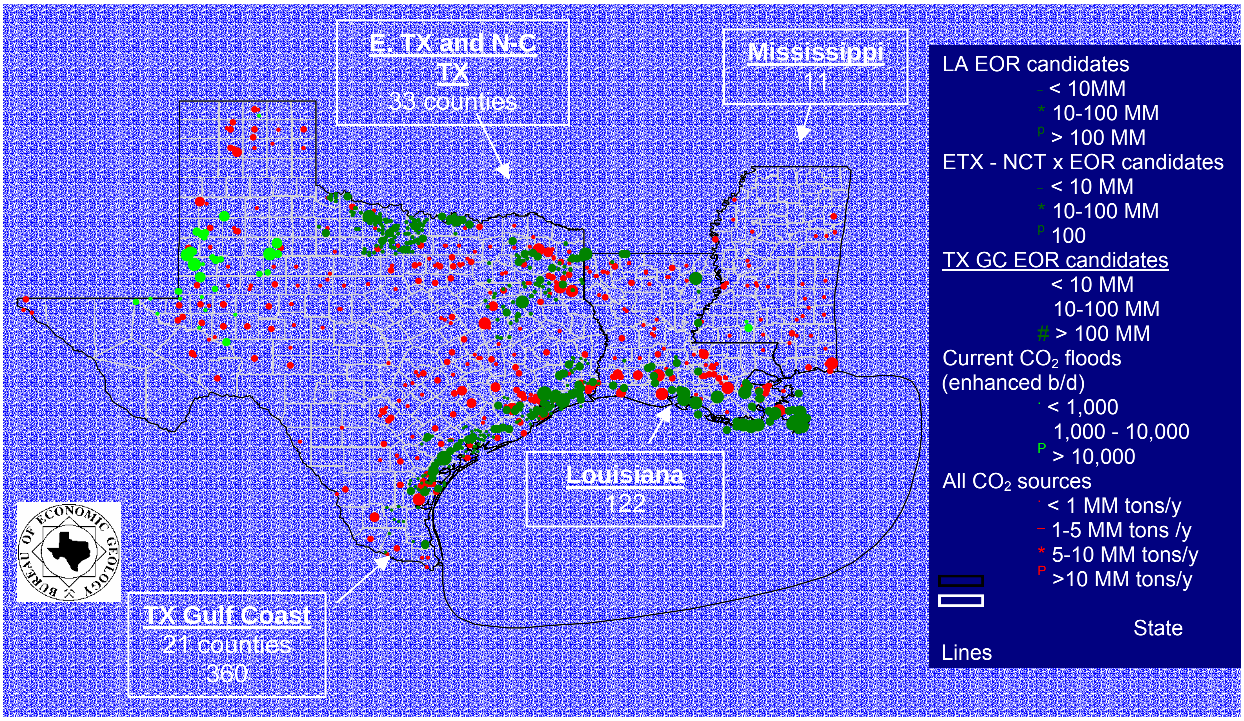
Basic data was compiled for characterization of conventional oil and gas reservoirs, coal bed methane reservoirs and saline aquifers. A GIS of geologic sinks in Alabama, Mississippi and the Florida panhandle was completed, and beta testing was conducted on an ArcView digital data product. The ArcView project features a unified front end that enables browsing of basic data and access to a series of GIS views that highlight specific types of sinks, as well as their proximity to anthropogenic CO_2 sources. A beta copy of the ArcView product was provided to MIT for incorporation to the NATCARB system.

Geological Sequestration - Oil & Gas Reservoirs

Oil and gas reservoirs have been characterized by TX BEG through digitally compiling in GIS the following: the *Atlas of Texas Major Oil Reservoirs* (Galloway and others, 1983) and the *Atlas of Texas Major Gas Reservoirs* (Kosters and others, 1989). Data from the Louisiana Geological Survey and the Mississippi Mineral Resources Institute were compiled for the Gulf Coast region of Louisiana and Mississippi.

Utilizing CO_2 for enhanced oil recovery provides an economic driver that can offset the cost of developing CO_2 capture, transport and injection infrastructure. Figure 12 shows EOR potential in Texas, Louisiana and Mississippi.

Figure 12. Value-added Storage Opportunities for Enhanced Oil Recovery



Extensive work by the TX BEG reveals that, within the South-central and southeastern areas of the SECARB region, opportunities exist for carbon sequestration with positive economic impacts. This can result from the deployment of enhanced oil recovery initiatives that utilize anthropogenic CO_2. TX BEG noted that currently 2-billion cubic feet per day of CO_2 is injected for EOR in the United States. Anthropogenic sources account for approximately 20% of the total. Currently this represents 66 active projects with 205,877 barrels of oil per day (approximately 4% of U.S. production). TX BEG estimates that sequestration volumes available in CO_2 – EOR (10% recovery) are 473 million metric tons in Texas and 5763 million metric tons in the United States.

ARI/Kuuskraa and others also have determined that increases are possible in the levels of CO_2 – EOR production in the United States. It is evident that significant successes in the Permian Basin have accounted for steady increases in daily oil recovery. TX BEG has noted that 50 of the 66 active CO_2 – EOR projects are located in the Permian Basin.

TX BEG has determined that opportunities exist for expanding CO_2 – EOR into east central and southeast Texas, Louisiana and southern Mississippi. Based upon the characteristics of reservoirs in the area designated by Denbury as the "Eastern Gulf Coast," SECARB has designated this area as having the most promising opportunities for expanding the use of anthropogenic CO_2 for enhanced oil recovery. The model that has been developed by TX BEG to describe the most promising target area, in conjunction with EOR, is the "stacked storage" target. This consists of oil producing formations that are suitable for CO_2 EOR that are "stacked" with saline formations. In the stacked storage target, much of the cost of infrastructure can be off set by EOR production. CO_2 used for EOR will be recycled in a closed-loop production mode and ultimately the oil producing reservoirs will be sealed and pressurized with stored CO_2. Once filled, the CO_2 injection will be repositioned from the depleted oil reservoirs to stacked saline formations using the same infrastructure.

Geological Sequestration - Brine Formations

SECARB worked with state geologic surveys, universities and private companies to compile information on saline formations within the region. Figure 13 provides an overview of geologic provinces in the SECARB region. 14 through Figure 18 provide depictions of various formations within the SECARB region. The review of potential saline targets was focused upon formations that exist below 2400 feet. The reason for this approach was to consider the economic benefits of injecting CO_2 as a supercritical fluid and, generally pressure and temperature conditions are favorable below 2400 feet.

The volume of formations available below approximately 2400 feet is extremely limited or poorly defined in the Atlantic Coastal Plain, Piedmont and Blue Ridge Thrust Belt. The Appalachian Basin has favorable characteristics at the northeastern edge of the region, deteriorates due to outcropping through Tennessee and improves near the Cincinnati Arch and Black Warrior Basin. The Gulf Coast Basin and Louisiana-Mississippi Salt Basins are characterized by the largest volumes of deep storage capacity. East Texas, Louisiana and Mississippi also have “stacked” oil and gas/saline reservoirs that can provide economic benefits to CO_2 storage.

Figure 13. Geologic Provinces of the SECARB Region.

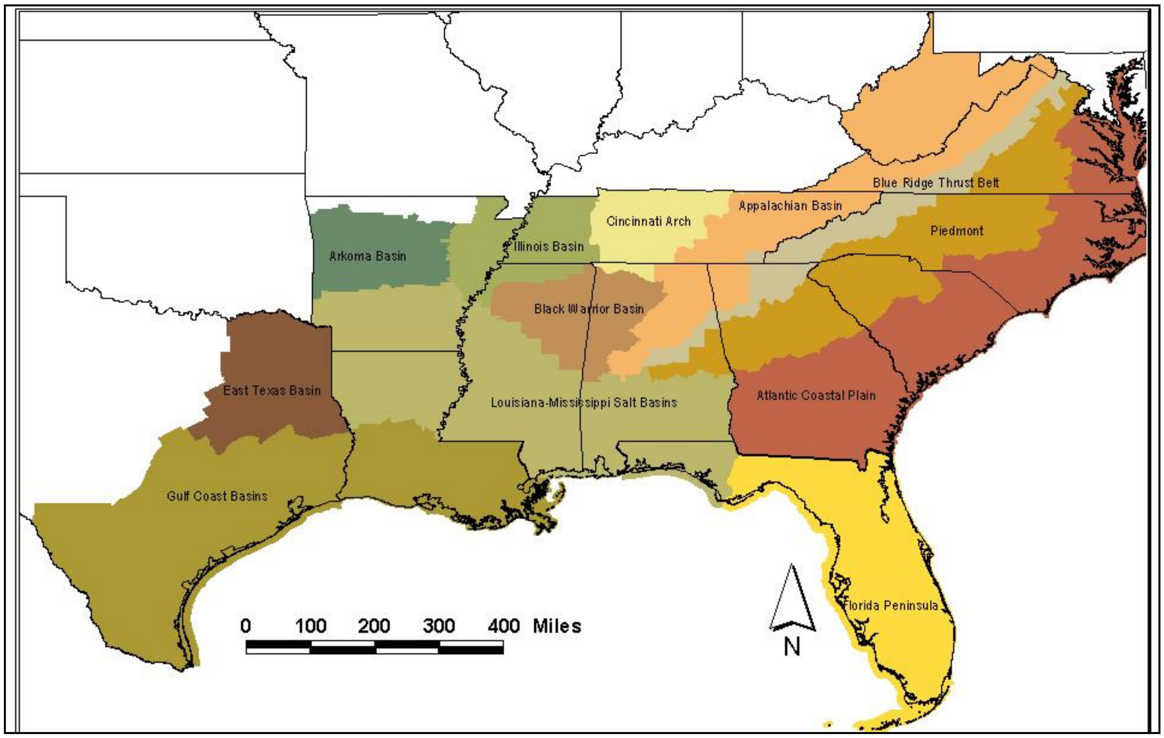


Figure 14. Inventory of Selected Prospects – Southern Appalachian Plateau and Basin

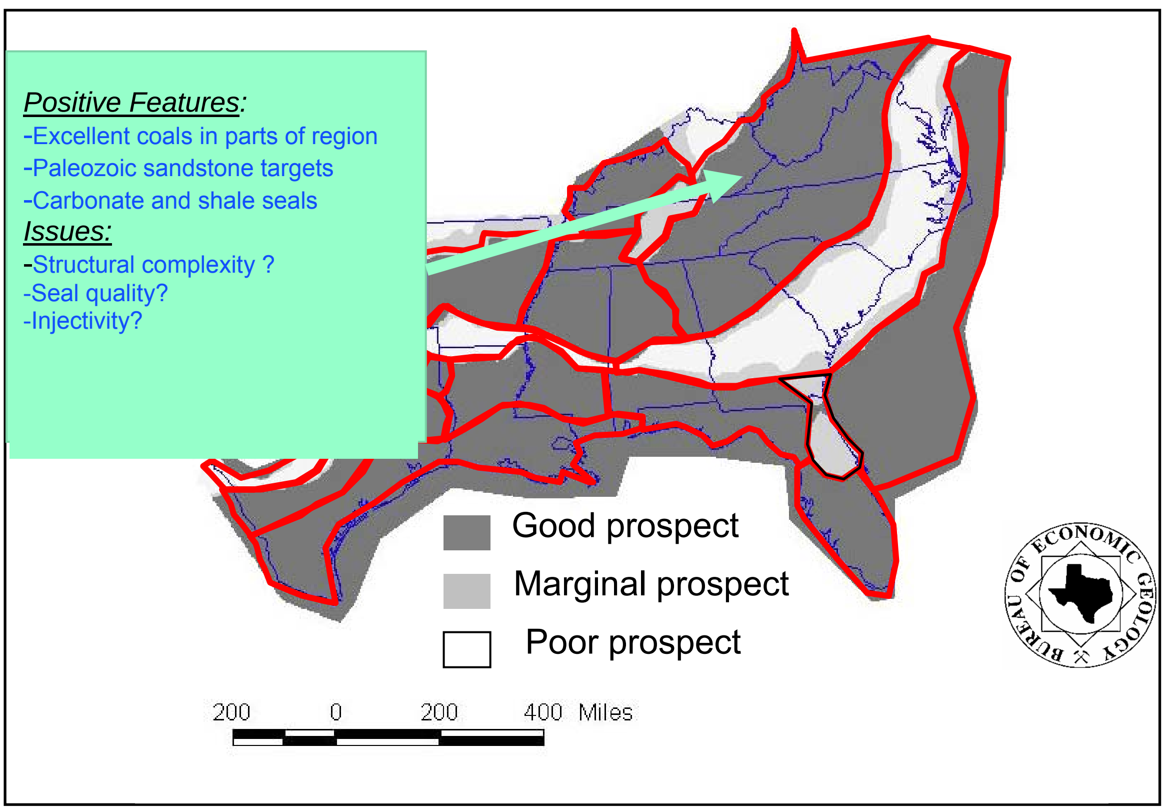


Figure 15. Inventory of Selected Prospects – Central Appalachians

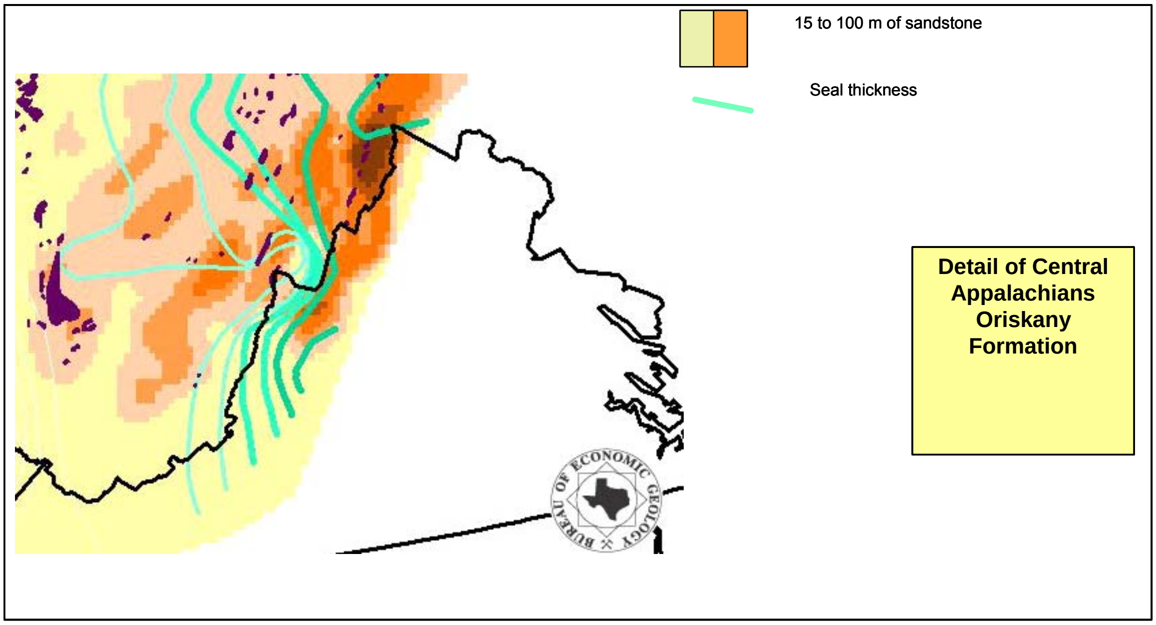


Figure 16. Inventory of Selected Prospects – South Florida Basin

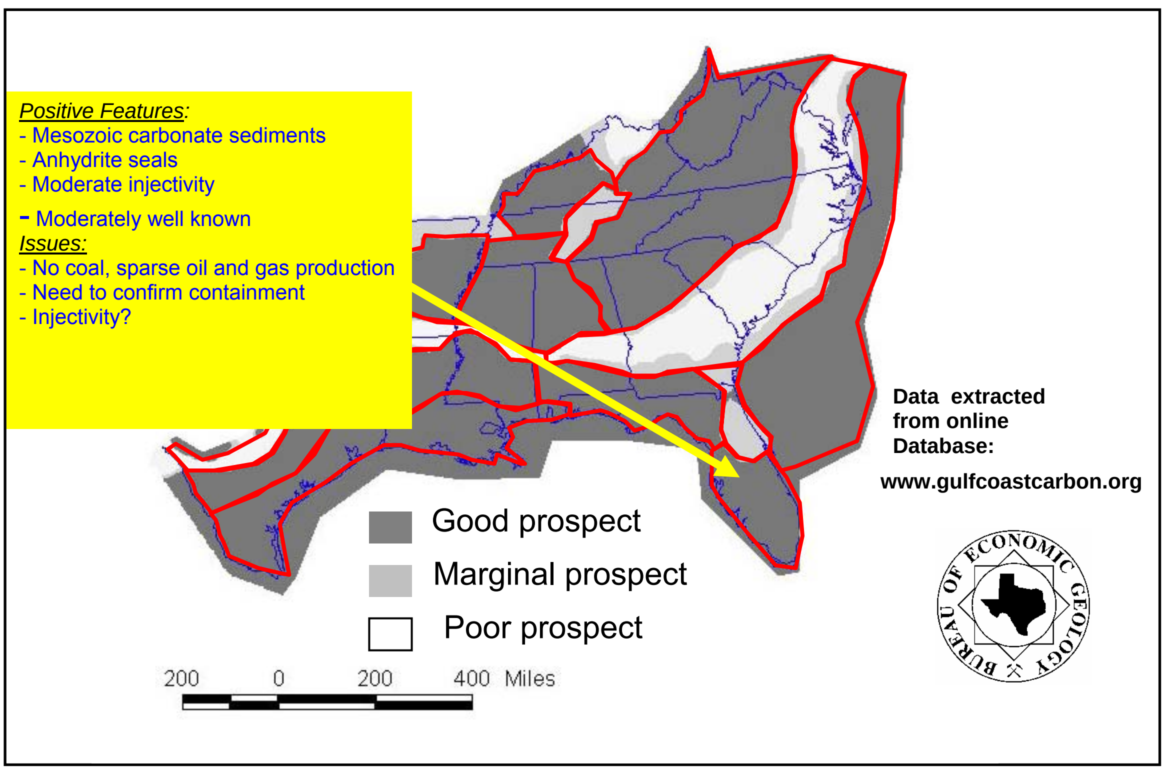


Figure 17. Inventory of Selected Prospects – Brine Targets in Florida

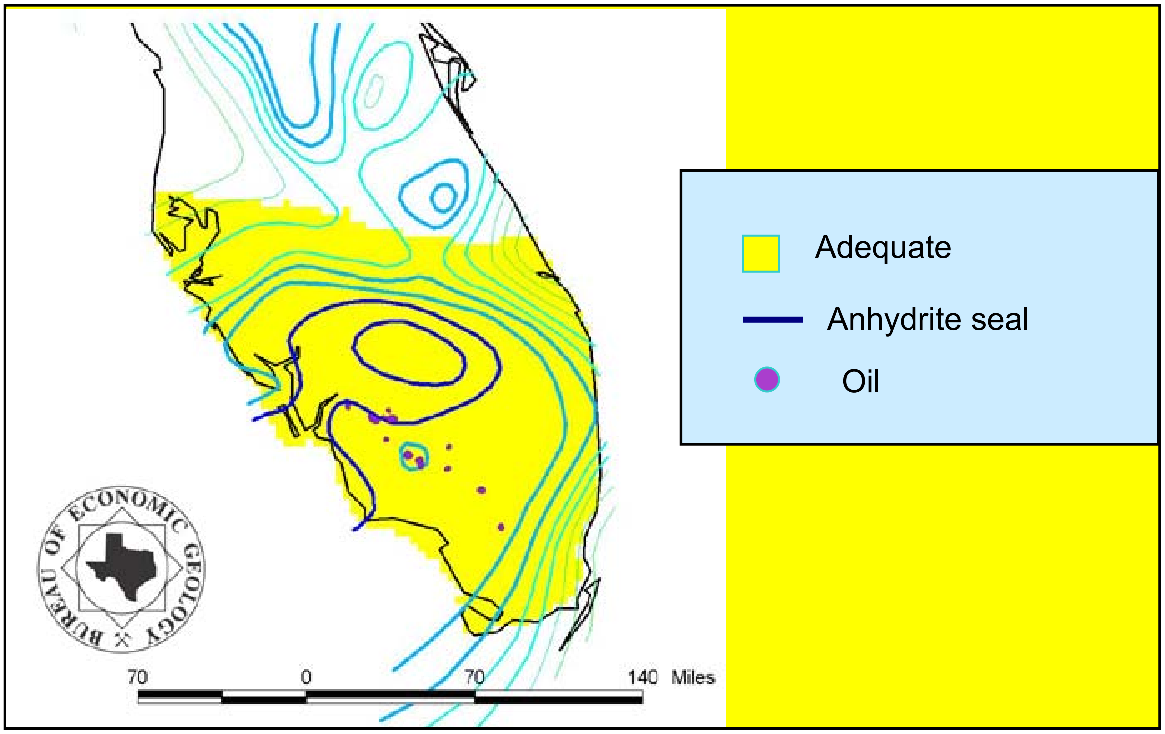


Figure 18. Inventory of Selected Prospects – Gulf Coast Basin

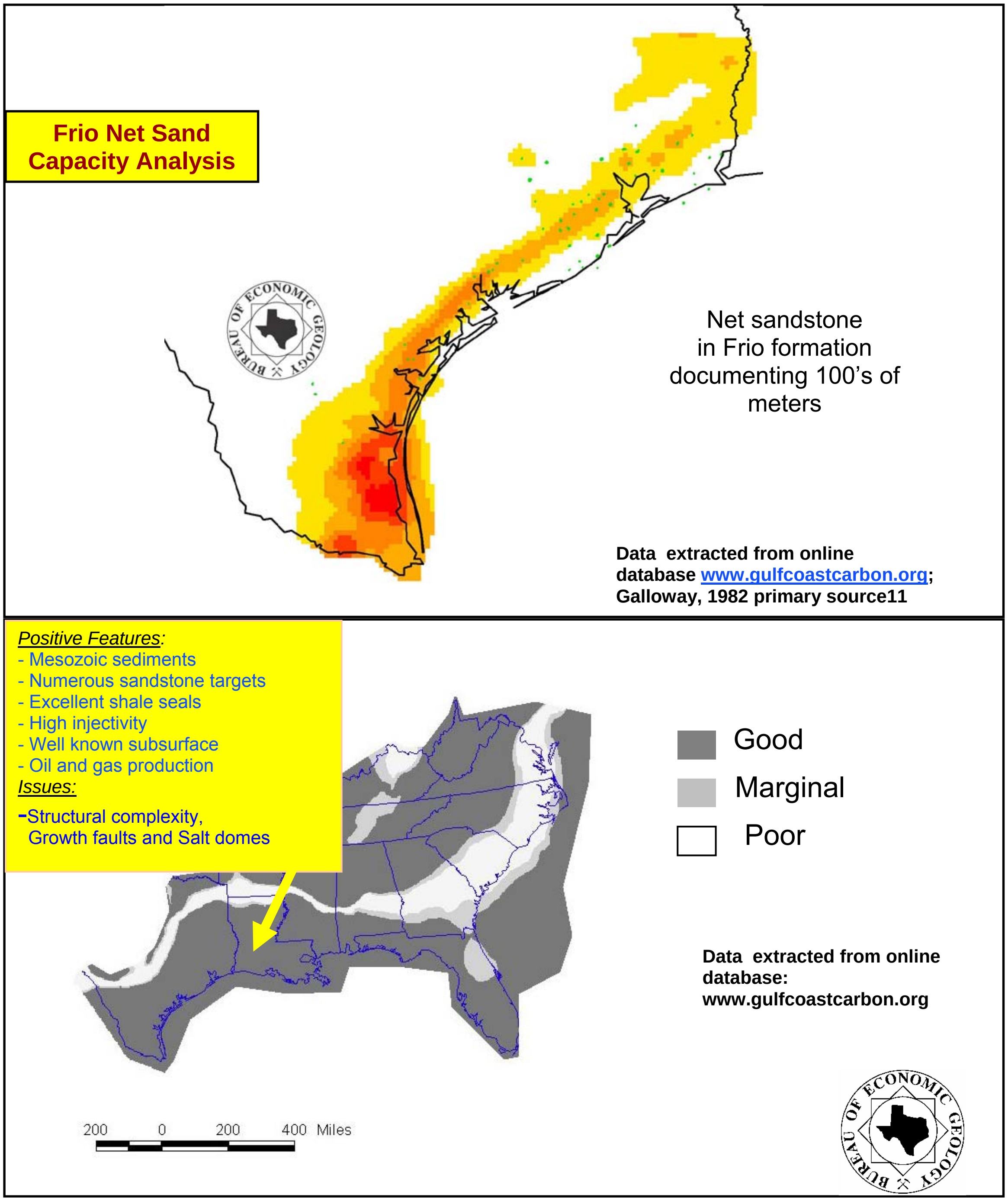
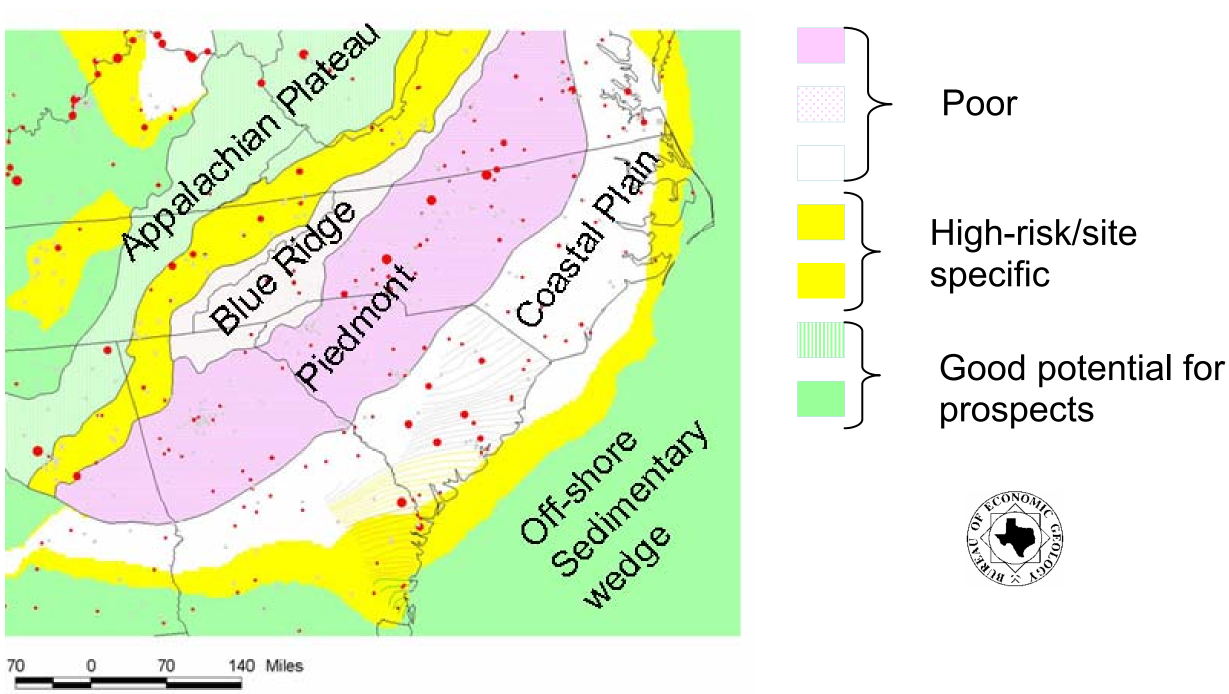


Figure 19 is an example of work performed by the TX BEG for SECARB to assist in depicting the nature and extent of sequestration potential in areas that lack data. These areas, while potentially suitable for long-term sequestration, are considered high-risk candidates for field demonstrations. In addition, the preliminary analysis supports the position that further characterization of the SECARB region is warranted. In some cases the additional analysis will be needed to substantiate and document the lack of suitability of particular areas.

Figure 19. Preliminary Prospects of Geological Storage



Database and GIS Tools

SECARB conducted an inventory of major CO_2 sources and sinks for the partnership region. The information resides on SECARB's database and is connected to the NATCARB database. The Partnership has refined GIS algorithms and tools for the geographic area, including:

- A tool for source/sink matching;
- A sink capacity tool; and
- Three costing algorithms for capture, transportation and injection.

Calculating CO_2 Storage Capacity

The generic formula for calculating reservoir volume is:

$$Q = V * p * e * \rho_{CO_2}$$

where

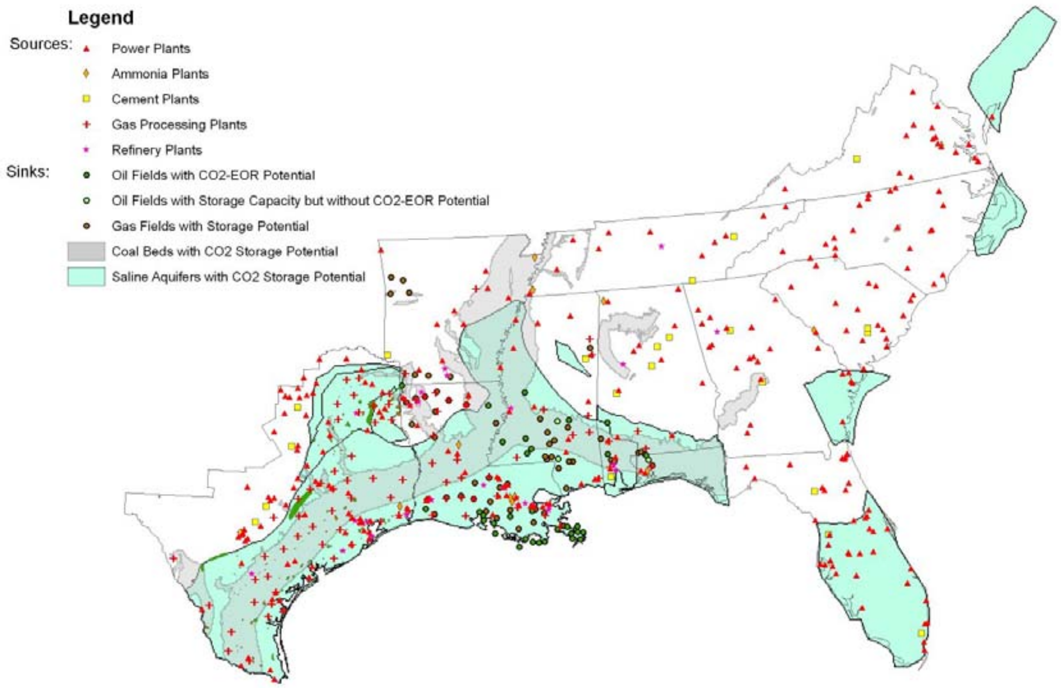
Q	= storage capacity of the reservoir ($MtCO_2$)
V	= total volume of reservoir (km^3)
p	= reservoir porosity (%)
e	= CO_2 storage efficiency (%)
ρ_{CO_2}	= CO_2 density (kg/m^3)

The reservoir volume and porosity are required inputs from the geologic data sets. The CO_2 density is calculated from the reservoir temperature and pressure (which are either obtained directly from geologic data sets or estimated from reservoir depth). The storage efficiency reflects the fact that CO_2 will flood only part of the reservoir. It has a typical range of between 2-30%. Storage efficiency estimates can be obtained from detailed reservoir simulations. However, this is beyond the scope of the Phase I screening analysis.

Source/Sink Matching

The SECARB team identified three types of potential geological storage sinks for CO_2 sequestration in the SECAB region: hydrocarbon (oil & gas) reservoirs, saline aquifers, and coalbeds. The database was based on the best information available during Phase I and will be continually updated in Phase II as more detailed data sets are developed. The storage capacity estimation methods in the JOULE II report (Holloway, *et.al.*, 1996) were adapted as the baseline models in estimating the CO_2 storage capacity for hydrocarbon reservoirs and saline aquifers, while the methodology developed by Reeves (2003) was used as the baseline model in estimating the CO_2 storage capacity for coalbeds. When necessary, these baseline models were modified to accommodate incomplete data sets contained in the current database. The modified models were then applied to estimate the CO_2 storage capacity for each candidate CO_2 sink.

Figure 20. CO_2 Sources and Sinks in the SECARB Region



After identifying the CO_2 sources and candidate sinks, the team then evaluated the CO_2 sequestration potential in the SECARB region by analyzing the matching between sources and sinks. Figure 20 shows the distribution of CO_2 sources and sinks that were considered in the source-sink matching analysis. Table 13 summarizes the CO_2 capture capacity from these sources (over 25 years) and the CO_2 storage capacity for these sinks by category. After excluding sources with CO_2 emissions below certain scales[1], the source data set considered in the matching analysis was restricted to 316 power plants and 103 non-power facilities. Over an assumed 25 year project lifetime, a total amount of 34 Gt of CO_2 from these facilities would need to be sequestrated. After excluding sinks with less than 5 Mt of storage capacity[2], the regional CO_2 storage capacity was estimated to be at least 504 Gt[3].

[1] Power plants with design capacity less than 100 MW_e and gas processing plants with design capacity below 300mmcfd are excluded.

[2] 5 Mt is the minimum capacity requirement for a sink to store the 25-year cumulative amount of CO_2 that can be captured from any facility in the interested source set.

[3] Due to incomplete datasets, the study didn't evaluate the CO_2 storage capacity in coalbeds except for Black Warrior Basin (see Section 3.3 for details).

Table 13. CO_2 Capture Capacity for Sources and Storage Capacity for Sinks Considered in the Matching Analysis

Field Group		Number of Fields	CO_2 Capture Capacity (Gt)[1]	CO_2 Storage Capacity (Gt)
Sources	Power Plants[2]	316	31.6	-
	Non-power Stationary Sources[3]	103	2.4	-
	Total	419	33.9	-
Sinks[4]	Oil Fields w/ EOR potential	74	-	1.9
	Oil Fields w/o EOR potential and Gas Fields	246	-	3.6
	Coal Beds[5]	n.a	-	0.3
	Aquifers	n.a	-	497.8
	Total			503.6

Note:
1. Project lifetime 25 years.
2. Only design capacity over 100MW$_e$ included.
3. Only includes ammonia, cement, gas processing, and refineries. Also, for gas processing facilities, those with design capacity less than 300 mmdcfd were excluded.
4. Only CO_2 storage capacity over 5 Mt included.
5. Only coalbed methane data in Black Warrior Basin, Alabama from AGS included in the estimate.

Table 14. Annual CO_2 Storage Capacity (Mt/y) of Various Sinks by Straight-line Distance from Source to Sink

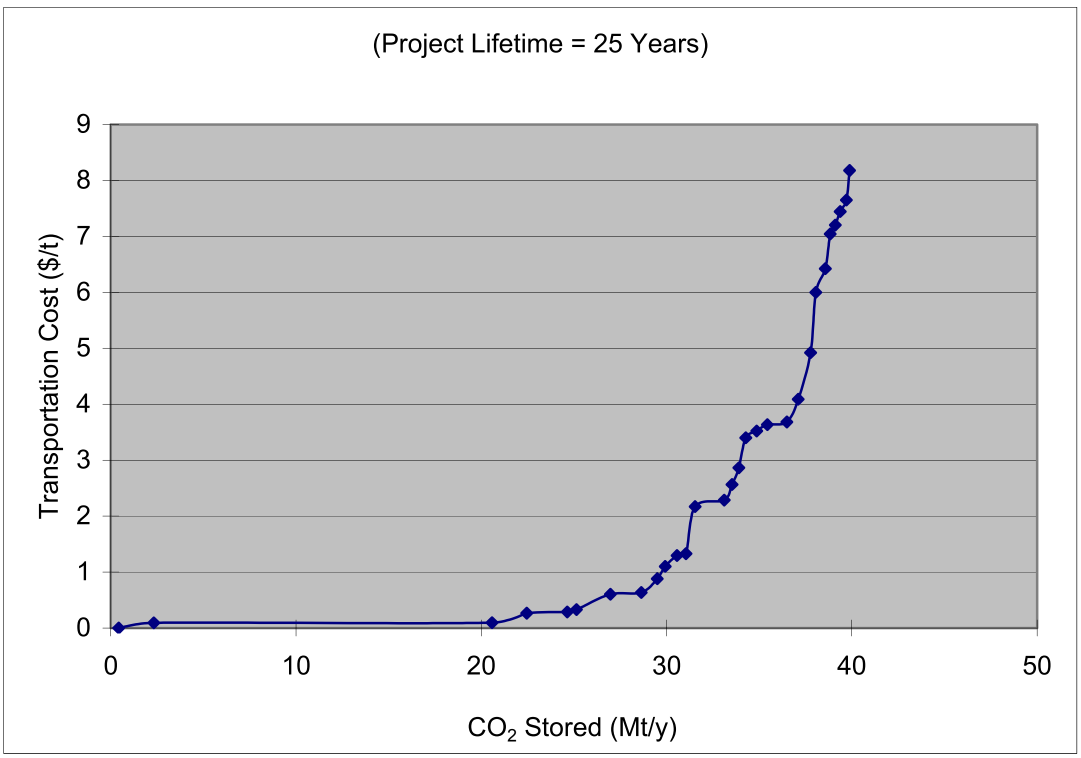
Sink Type	Straight Line Distance from Source to Sink		
	50 km or less	100 km or less	250 km or less
Oil & Gas Fields with EOR Potential	349	484	675
Oil & Gas Fields	507	598	726
Coalbeds	606	856	1,190
Aquifers	794	867	1,125
All Sinks	972	1,143	1,357

Note:
1. The total annual CO_2 storage rate was 1, 357 Mt.
2. Sinks with less than 5 Mt storage capacity were excluded from the analysis.

As a preliminary analysis, the team performed a straight-line distance based matching for the entire SECARB region, connecting each source to its closest sink in terms of straight-line distance. In this preliminary exercise, neither the optimal pipeline path nor the sink's storage capacity constraints were considered. The straight-line distance matching analysis was performed for each of the four different groups of eligible sinks and a combination of them altogether. Table 14 summarizes the matching results based on the straight-line distance in terms of annual CO_2 storage capacity by marginal straight-line distance. If EOR sites were the only sinks used for sequestration, only half of the CO_2 sources (by volume) could be matched with a sink that is less than 250 km from the source. If all sink types were considered for sequestration, however, then all of the CO_2 sources could be matched with appropriate sinks within 250 km from the source. More than 70% of the sources (by volume) would find their nearest sinks within 50 km.

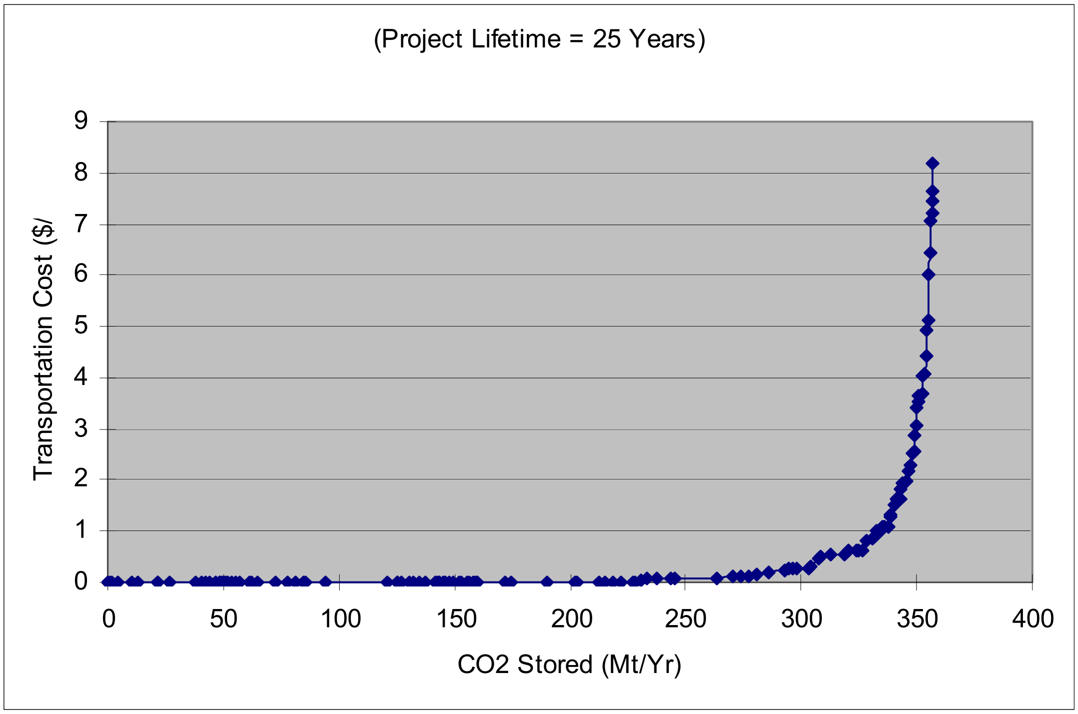
The SECARB team also conducted a GIS-based method of matching sources and sinks considering the optimal pipeline route selection and sink's capacity constraint. The pipeline construction costs vary considerably according to local terrains, number of crossings (waterway, railway, highway), and the traversing of populated places, wetlands, and national or state parks. In order to account for such obstacles, the locations and characteristics of these obstacles were loaded into the spatial database and were used to construct a single aggregate transportation obstacle layer. In contrast to the distance-based matching analysis, this least-cost matching analysis links each CO_2 source to a least cost geological sink based on sum of the transportation cost associated with the least-cost path and the injection cost subject to the sink's capacity constraint. An iterative algorithm was used to approximate an optimal system solution. Due to the limited availability of detailed sink data for the SECARB region, a demonstration of least-cost matching analysis was performed for eastern Texas where the data sets are relatively rich.

Figure 21. Marginal Transportation Cost in eastern Texas Oil Fields with EOR Potential



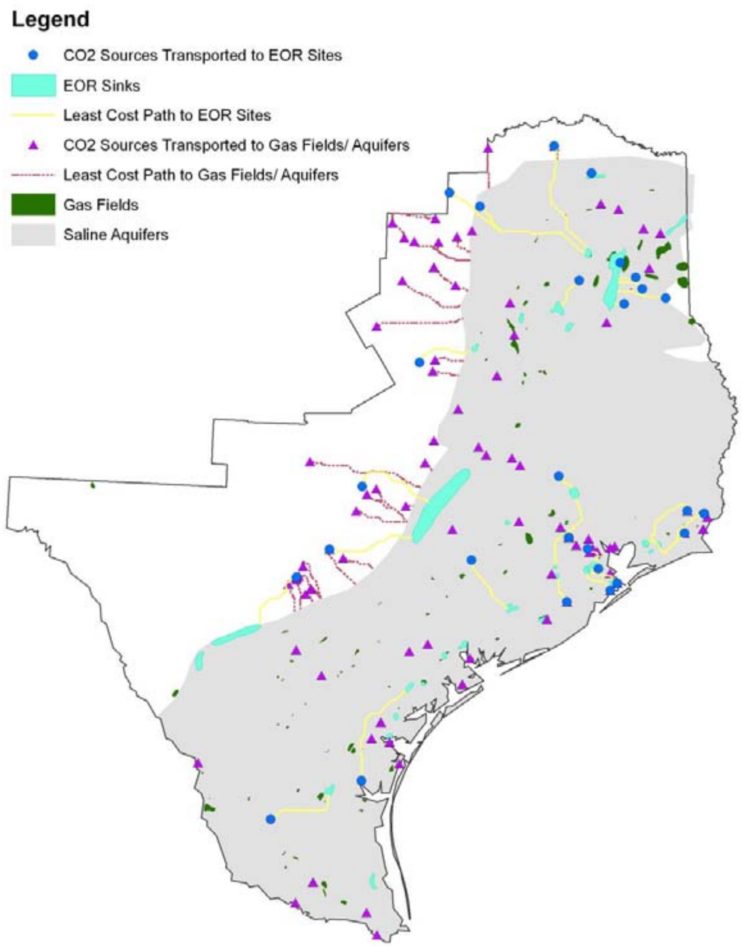
The least-cost source-sink matching analysis for eastern Texas was conducted in two stages. In the first stage, only EOR sites were included as candidate sinks. The cost calculation assumed a credit of \$16/t CO_2 for EOR injection in place of the injection cost. With the assumption of a constant CO_2 credit, the optimization algorithm only considers minimizing the overall transportation of the network system. Figure 21 shows the marginal transportation cost in oil fields with EOR potential. The annual CO_2 storage rate in EOR sites is estimated to be 40 Mt. While the maximum transportation cost is around \$8.2/t CO_2, about 30 Mt CO_2 can be transported to EOR sites annually at transportation cost less than \$1/t CO_2.

Figure 22. Marginal Transportation Cost for all Sources in Eastern Texas



After allocating the EOR storage capacity to appropriate sources, the remaining unmatched sources were assigned to hydrocarbon fields without EOR potential and saline aquifers in the second stage. Figure 22 shows the marginal CO_2 transportation cost in all sinks. Extending the sinks to include non-EOR hydrocarbon fields and saline aquifers, the annual CO_2 storage rate in eastern Texas becomes 357 Mt, among which about 330 Mt can be transported to a sink with transportation cost less than \$1/t CO_2. Figure 23 shows the pipeline routes connecting each source to its assigned sink by the least-cost matching. It is of interest to note that some sources right on top of aquifers were still assigned to EOR sites as the EOR credit and the saved injection cost outweighs the added transportation cost.

Figure 23. Source-Sink Matching Final Result



Estimating CO_2 Injectivity and Injection Cost

SECARB implemented a method into the GIS to calculate the injection costs. First, the CO_2 injectivity per well is calculated based on surface injection pressure, reservoir pressure, permeability, depth and thickness (based on the work of Law, D. and S. Bachu, "Hydrogeological and numerical analysis of CO_2 disposal in deep aquifers in the Alberta sedimentary basin," *Energy Convers. Mgmt*., **37**:6-8, pp. 1167-1174, 1996.). Reservoir permeability, depth and thickness are needed from the geologic data. Reservoir pressures can be obtained from the geologic data or estimated from depth. Injection pressure is set so as not to exceed the fracking pressure (or may be set by regulation in some cases). Second, using the CO_2 injectivity, the number of wells required for a given CO_2 flow rate is calculated. Finally, a set of capital and O&M cost factors are used to determine the cost based on well numbers. Details of this method can be found in: *Heddle, G., H. Herzog and M. Klett, "The Economics of CO_2 Storage," MIT LFEE 2003-003 RP, August (2003).* http://sequestration.mit.edu/pdf/lfee_2003-003_rp.pdf.

SECARB added an alternate methodology to Law and Bachu (1996) based on an ARI method. Both methods give similar results for initial injection rates. The advantage of the ARI model is that it reconciles the problem that CO_2 injectivity varies over time as the reservoir pressure rises due to the injection. The same reservoir parameters are used as input in both methods.

Estimating CO_2 Pipeline Transportation Cost

The transportation cost model takes the source-sink matching as a priori and estimates the CO_2 pipeline transportation cost at three levels: (1) one source to one sink; (2) many sources to one sink without route-sharing; and (3) many sources to one sink with route-sharing.

For the simplest case of one-source-to-one-sink connection, the estimation consists of three steps. First, the pipeline diameter is calculated based on the CO_2 flow rate. Second, the least-cost route is selected based on the relative cost factors assigned to various transportation obstacles for both economic and environmental concerns. The identified transportation obstacles include populated places, wetlands, national and state parks, waterways, railroads, and highways. Finally, the base case pipeline construction cost, additional obstacle crossing cost and O&M cost are assigned to estimate the levelized CO_2 transportation cost. More details are presented in Appendix K of this report.

Matching CO_2 Sources and Sinks

The source-sink matching analysis takes into account three factors: capacity, injection cost, and transportation cost (assuming CO_2 capture cost is source-specific and exogenous to the GIS system). SECARB's analysis occurs at three levels: (1) starting from a particular source, search for the least-cost sink for this source; (2) starting from a targeted sink, search for a set of sources with the lowest overall cost to fill the sink's capacity; (3) for a set of multiple sources and multiple sinks in a study region, design a source-sink matching network to minimize the overall cost for CO_2 transportation and injection in the system.

Task 3: Identify and Address Issues for Technology Deployment

Task 3.0 addressed technology deployment and resulted in a preliminary assessment of safety, regulatory and permitting requirements, public perception, ecosystem impacts, monitoring and verification requirements and other potential issues associated with wide scale deployment of promising regional opportunities. A listing of activities and deliverables related to this task is outlined below.

3.A. Assessment of safety, regulatory and permitting requirements. A preliminary assessment of safety, regulatory, and permitting (regulatory) requirements was conducted within the region and reported in the "Semi-Annual Technical Progress Report – Regulatory, Permitting, Safety and Accounting" (Deliverables Appendix Document, Volume I, Bookmark 3.A). The assessment was prepared in consultation with state public utility commissions, oil and gas commissions and environmental compliance agencies. It provides a baseline on regulatory requirements in member states and highlights future regulatory needs for sequestration.

3.B. Regional Action Plans and early implementation, where possible. Action Plans were developed and are presented in Section 6 of this report (also see Deliverables Appendix Document, Volume II, Bookmark 3.B). Early implementation of safety, regulatory, and permitting requirements was not possible, due to (1) the need to down-select to specific sites for field verification of sequestration technologies and (2) the requirement that no field investigations or field activities be initiated until DOE has completed and approved a NEPA review for field locations where deployment will occur.

3.C. Survey instrument & focus group results. SECARB conducted a preliminary assessment of public perception issues within the region associated with wide scale deployment of promising CO_2 capture, transport and storage opportunities. Survey instruments were developed and a focus group session was conducted (Deliverables Appendix Document, Volume I, Bookmark 3.C).

3.D. Regional survey methodology & results. A telephone survey was conducted within the SECARB region. Information was obtained relative permitting processes for energy projects; general public, citizen group and environmental group reaction and perception to energy-related projects; current energy generation or environmental protection issues; and hurdles to energy generation and environmental protection initiatives. Results from the survey were tabulated and analyzed (Deliverables Appendix Document, Volume I, Bookmark 3.D).

3.E. Regional Action Plans and early implementation, where possible. Action Plans related to public perception were developed and are presented in an Augusta Systems report entitled "Phase I Final Report – Outreach" (Deliverables Appendix Document, Volume I, Bookmark 3.E). Analysis of concerns and perceptions led to the development of key message points for early implementation (Deliverables Appendix Document, Volume I, Bookmark 6.F)

3.F. Action Plan development and early implementation, where possible. Action Plans were developed and are presented in Section 6 of this Draft Final Report (also see Deliverables Appendix Document, Bookmarks 3F.1 in Volume I and 3.F2 in Volume II). Early implementation of safety, regulatory, and permitting requirements, at the site level, was not possible, due to (1) the need to down-select to specific sites for field verification of sequestration technologies and (2) the requirement that no field investigations or field activities be initiated until DOE has completed and approved a NEPA review for field locations where deployment will occur.

3.G. Integrated report based upon preliminary assessment of ecosystem. Susan Rice and Associates (Rice) developed a report that assessed the potential ecosystem impacts of carbon sequestration as it relates to the environment and health and safety (Deliverables Appendix Document, Volume I, Bookmark 3.G). The preliminary assessment identified and addressed issues that could result in ecosystem impacts.

3.H. Action Plan to address ecosystem issues. Susan A. Rice and Associates (Rice) developed a report on the Environmental Toxicity of Carbon Dioxide (Deliverables Appendix Document, Volume I, Bookmark 3.H). The findings from this report were taken into consideration when determining the monitoring and verification requirements for the field verification Action Plans presented in Task 6.0 of this report. CO_2 can enter an ecosystem via the air, water, or soil. Each organism has its own characteristic response to CO_2 that is dependent on the concentration of CO_2, route and duration of exposure, life stage at exposure, environmental conditions (e.g., oxygen concentration, temperature, humidity), and other factors. Vast regions of the original ecosystems in the SECARB region have been converted, and conservation of the little remaining original ecosystem, including many endangered plant and animal species, is of great importance.

3.I. Report on down selection of instrumentation and QA/QC for CO2 quantification. Mississippi State University's Diagnostic Instrumentation and Analysis Laboratory (DIAL) assessed monitoring and verification requirements for SECARB (Deliverables Appendix Document, Volume I, Bookmark 3.I). DIAL reviewed subsurface, surface and above-surface MM&V categories of technology and down-selected techniques for monitoring CO_2 at the source, during transport, and in various sequestered forms. In addition, DIAL addressed quality assurance/quality control methods for ensuring valid measurement of CO_2 for the intended application.

3.J. Develop MM&V Action Plans for transport and sequestration. DIAL developed an Action Plan that addressed MM&V monitoring requirements needed in field verification of carbon sequestration techniques (Deliverables Appendix Document, Volume I, Bookmark 3.J). Requirements for instrumentation and protocols were addressed, with emphasis on real-time portable CO2 monitoring capability.

3.K. Early implementation of Action Plan, where possible. Action Plans related to MM&V were developed and are presented by DIAL (Deliverables Appendix Document, Volume I, Bookmark 3.J). Early implementation of to address MM&V, at the site level, was not possible due to (1) the need to down-select to specific sites for field verification of sequestration technologies and (2) the requirement that no field investigations or field activities be initiated until DOE has completed and approved a NEPA review for field locations where deployment will occur.

3.L. Field Test plan for verification of source/sink relationship. DIAL developed an approach for field test plans for the verification of source/sink relationships (Deliverables Appendix Document, Volume II, Bookmark 3.L). The approach is based upon the use of existing predictive models, remote sensing techniques and methods for capturing and sampling CO2 that is being injected and differentiating the target CO2 from background CO2.

Task 3 Highlights

SECARB developed action plans to overcome the issues identified in the preliminary assessment of safety, regulatory, permitting and accounting frameworks within the region. This plan allows for wide-scale deployment of promising terrestrial and geologic sequestration approaches, such as specific capture, transport, injection and storage approaches. Through the efforts of the team members, SECARB has worked to advance this goal and the overall mission during Phase I of the RCSP initiative. As a result of the unique structure of the SSEB, which is the Nation's only regionally-focused, federal-state energy compact, SECARB has been well-positioned to research and develop regulatory, permitting and accounting frameworks for associated multi-year action plans.

Research and analysis has been performed on relevant state and federal statutes and regulations applicable to sequestration regulatory, permitting and safety matters. This research involved direct examinations of applicable statutes and regulations related to both geologic and terrestrial sequestration applications, as well as interaction with state legislators and regulators responsible for enacting and implementing regulatory regimes. This research and analysis concentrated on geologic sequestration related to direct carbon dioxide injection into geologic formations, enhanced hydrocarbon recovery using carbon dioxide and governance of the associated deep well injection classes. Also, Augusta Systems participated, on behalf of SECARB, with the Interstate Oil and Gas Compact Commission Geological CO_2 Sequestration Task Force to ensure that SECARB approaches would converge with recommended national approaches.

Key analysis regarding terrestrial sequestration focused on permitting and regulatory barriers and/or incentives to various field applications that could be implemented. This activity also used selected scholarly articles and papers related to regulatory and permitting issues for analogous practices.

In another effort to ensure that all RCSPs, including SECARB, engaged in regulatory, permitting, safety and accounting framework analysis and development activities with an appropriate base of background knowledge about regulatory and legal activities, NETL coordinated and managed RCSP Regulatory Compliance and Liability Issues

Working Group meetings. As a result of these quarterly meetings and calls, as well as the IOGCC-led effort, SECARB and the other partnerships are working to ensure that common regulatory and accounting approaches are being developed throughout the RCSPs.

Further, Augusta Systems investigated emerging GHG accounting frameworks. As no universally-accepted accounting standard exists for GHG emissions and emissions reduction accounting, this research focused on tracking the methodologies and protocols presently in practice internationally and nationally. This study included the current requirements of and contemplated amendments to the DOE Voluntary Reporting of Greenhouse Gases Program, established under Section 1605(b) of the Energy Policy Act of 1992. SECARB also examined methodologies and protocols under various international efforts.

Measurement, Monitoring and Verification

During SECARB Phase I, the Mississippi State University completed an initial survey of measurement, monitoring and verification (MM&V) technologies for the SECARB partnership. In addition, emerging technologies that will play an important role within five years were identified. MM&V needs that are either unfulfilled, or where there are significant opportunities for improvement, were noted.

Goals for MM&V technology

DOE goals for MM&V technologies are given as:

- By 2006, DOE will apply promising MM&V technologies in several field tests or commercial applications.
- By 2008, MM&V protocols will enable 95% of CO_2 uptake in a terrestrial ecosystem to be credited, and represent no more than 10% of the total sequestration cost.
- By 2012, MM&V protocols will enable 95% of CO_2 injected into a geological reservoir to be credited, and represent no more than 10% of the total sequestration cost.

Therefore, MM&V technologies were evaluated in terms of their ability to contribute to meeting those goals and in terms of effectiveness in achieving certain specific aims including measurement of the amount of CO_2 stored at a specific sequestration site, monitoring of the site for leaks/deterioration over time, (i.e., storage stability, and potential harm to the ecosystem), and a means to provide a warning or alarm upon CO_2 leakage and possible ecological damage.

Categories of MM&V

MM&V technologies can be classified into three broad application categories: subsurface, surface, and above-surface. Subsurface MM&V involves tracking the fate of the CO_2 within the geologic formations underlying the earth and its possible migration to the surface. This area also encompasses developments to mitigate CO_2 leakage, should it occur. Surface MM&V involves tracking carbon uptake and storage in the topsoil as well as tracking potential leakage pathways into the atmosphere from the underlying formation. This area is especially challenging due to the difficulty of detecting small changes in concentration above the background emissions (~370 ppm) that already exist in the atmosphere. Above-surface MM&V is specific to terrestrial sequestration and involves quantification of the terrestrial carbon. DOE's MM&V R & D is aimed at developing site-deployable instrumentation, comprehensive computer models, and advanced protocols for each of these areas.

MM&V Technologies

Table 15 lists MM&V techniques applicable to different storage scenarios. The information was based on examination of the existing literature. The list is representative of tools available during the Phase I assessment. Additional information on instrumentation is being compiled by SECARB team members in conjunction with the Frio Brine project in Texas (Horvorka, et al., 2005).

Table 15. MM&V Techniques Applicable to Sequestrations

Geological sequestration		
Subsurface CO2 plume	Fluid movement monitoring	Surface based: 3D & 4D seismic imaging
		Borehole: Vertical Seismic Profile (VSP)
		Cross-Well Tomography
		Borehole and wellhead pressure sensors
	Near surface	Horizontal and vertical flow meters
		Streaming potential sensors
		Soil gas monitoring (LIBS, INS)
		Near IR Diode Laser Absorption Spectroscopy
Surface CO_2	Atmospheric	Standing Acoustic Wave Gas Chromatography
		Thermal Conductivity Sensors
		Gas Chromatography
		Chemical Reaction (Draeger tubes)
		Satellite Measurements
		Airborne Measurements (trace compounds)
Terrestrial Sequestration		
	Modeling	In-soil and above- ground carbon
		Ecosystem and landscape scale models
		Global models of terrestrial sink changes
	Measurements - Regional Monitoring	IR imaging
		Ameriflux network (and others)
	Measurements - Soil measurements	LIBS and INS
		Raman technology
		Isotopic measurements
		Microbial indicators

		Regional maps/estimates
		Traditional, dry combustion
	Above-surface carbon measurements	Forest inventories/ accounting
		Employing growth and yield models
		Aerial/satellite (Winrock method)
		Forest management techniques
		Traditional field measurements
Oceanic Sequestration		
		Gravitational measurements
		Seawater chemistry
		Diffraction
		NMR Spectroscopy
		Raman Spectroscopy

Important Technology Needs

There are two major development needs relating to MM&V technologies. The most important is cost reduction. While reliable estimates of overall costs are not available, recent experience suggests that the costs of MM&V for geologic sequestration far exceed DOE's 10% goal. It appears that the best way to achieve cost effectiveness is with a combination of less expensive instrumentation and modeling.

With regard to terrestrial sequestration soil carbon measurements are expensive owing to the lack of a readily deployable field system. While laser induced breakdown spectroscopy (LIBS) has shown potential, the system is not fully validated. The approach taken by SECARB's terrestrial partner Winrock for carbon in vegetation involves algorithms relating more expensive "standard" measurements and less expensive remote sensing measurements.

With regard to geologic sequestration, the most important need is for inexpensive and readily deployable downhole techniques. Direct CO_2 monitoring in a reservoir to determine system status is obviously desirable, but status indicators for such important variables as the pressure and temperature suitable for routine downhole deployment are lacking. It appears that techniques such as the ringdown spectroscopy being developed by MSU can provide the less expensive techniques needed for real-time downhole applications. In the longer term, nano-scale devices may also have great promise, assuming greatly reduced costs and increased ruggedness.

Development of a Real-Time Portable CO_2 Monitor

The objective of this effort is to explore a new technology to develop a real-time portable CO_2 monitor, which will detect CO_2 leakage, monitor the long-term stability of CO_2 storage and provide rapid response to help mitigate damage to the ecosystem in the unlikely event that a leak should occur. The new protocol also will be capable of being deployed in an aircraft to conduct geological surveys of atmospheric CO_2 at the regional and global levels, as well as tracking CO_2 migration in the atmosphere. With the capability to measure multiple species, the new protocol can also be used for monitoring other GHG emissions.

The CO_2 monitor under development at MSU, and being considered for field deployment by SECARB, is based on an ultra-sensitive and highly selective spectroscopic technique known as cavity ringdown spectroscopy[4] (CRDS). The potential advantage of CRDS is that it is capable of measuring small-scale variations in CO_2 concentrations over the high concentrations of CO_2 in the atmosphere. Based on the spectral calculations using HITRAN 96, a single temperature controlled semiconductor diode laser operating around 1650 nm was selected to cover some of the spectral fingerprints of CH_4, CO_2, and H_2O in the near-IR spectral region[5]. Ringdown spectra of atmospheric CH_4, CO_2, and H_2O were obtained with inexpensive ringdown mirrors under vacuum free conditions. A near IR laser diode was selected as the light source, which provided narrow linewidth, tunable, single mode laser output at ~ 1650 nm. Figure 24 shows the laboratory-level CRDS-based spectrometer.

Figure 24. A Standalone Unit for Atmospheric CH_4, CO_2, and H_2O

(a) Front view (b) Rear view

The absorption spectrum of atmospheric CO_2, CH_4 and H_2O, measured with this CRDS-based spectrometer, is shown in Figure 25. The atmospheric concentrations of CH_4, CO_2, and H_2O in a laboratory at MSU were determined to be 1.8, 350, and 11000 ppm,

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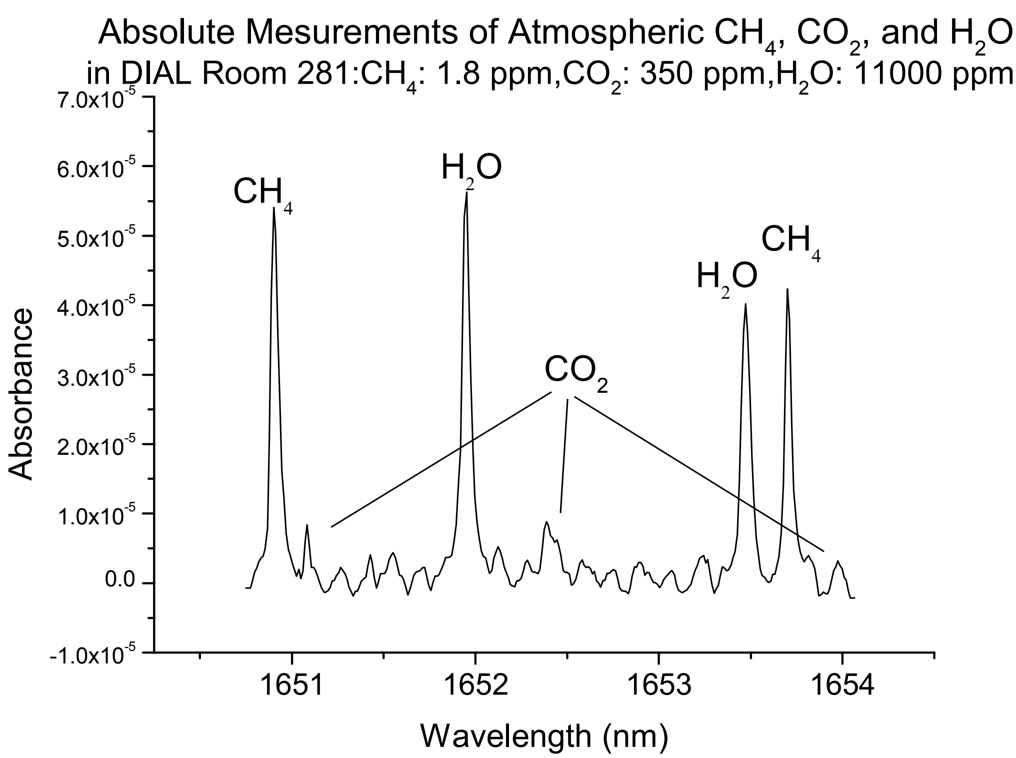
4 A. O'Keefe and D. A. G. Deacon, "Cavity ring-down optical spectrometer for absorption measurements using pulsed laser sources," Rev. Sci. Instrum. 59, 2544 (1988).

5 Wang, Chuji; Scherrer, Susan. T.; and Winstead C. B. "A simple method and device for control of cavity energy buildup and shutoff in cw-cavity ringdown spectroscopy: application for ringdown measurements of atmospheric CH_4, CO_2, and H_2O at 1.65 μm". (to be published).

respectively, from the recorded spectra. Results were compared with those from the theoretical simulations. The measured atmospheric concentrations of these molecules are in good agreement with the documented values in the literature, except for H_2O whose concentrations varied daily during the one-month measuring period (13000, 12500 and 11000 ppm on April 21st, 25th and 29th respectively). With these relatively inexpensive mirrors and a cavity length of 60 cm, the detection limits of methane and CO_2 at this wavelength are ~ 7 ppb and 50 ppb, respectively. The measurement accuracy is ~ 5%.

This work demonstrates that an inexpensive ringdown analyzer utilizing a single near-IR semiconductor diode laser can be developed for simultaneously monitoring atmospheric CH_4, CO_2 and H_2O. It should be noted that this laser diode was originally selected to demonstrate measurement of atmospheric methane. If another diode laser with wavelength output at ~ 1572 nm is selected, the detection sensitivity of CO_2 can be expected to improve by several orders of magnitude.

Figure 25. Ringdown Measurements of Atmospheric CH_4, CO_2, and H_2O using a NIR laser diode at ~ 1650 nm.



This work demonstrates that emission monitors for GHGs can be developed using the CRDS technique. Potential applications include leak detection of CO_2, long-term stability monitoring of CO_2 storage and rapid response to CO_2 leakage for mitigation means. The research can be furthered to determine isotopic ratios of carbon in CH_4 and CO_2 in the atmosphere to track the migration of greenhouse gases or to monitor gas emissions in methane-and carbon dioxide-related sites.

<u>Development of Fiber Pressure Sensors</u>

Implementation of effective controls in geological carbon sequestration require monitoring the condition of the injection well, such as well-head pressures and formation pressures. A rugged, deployable and cost-effective pressure sensor is needed. In addition, if the sensor has the ability to measure down-hole, then additional validation of reservoir models and the ability to verify that injected CO_2 is not subject to lateral or vertical migration can be demonstrated.

During the past twenty years, fiber optical pressure sensor technology has progressed rapidly - outperforming conventional pressure sensors with their high sensitivity, fast response, low cost, light weight, as well as immunity to electromagnetic interference. Currently, the most popular fiber pressure sensors are mainly based on fiber Fabry-Perot interferences (FFPI) or fiber Bragg gratings (FBGs). MSU has developed a technique for fiber pressure sensor development, using conceptually new approach -- fiber loop ring-down[6, 7] that shows promise and is under consideration for deployment in SECARB Phase II field verification.

This method is modeled after the ringdown concept; however, a conceptually new approach, which eliminates the dependence on an ultra-high reflectivity cavity, is used. This new fiber ringdown technique utilizes an optical resonator, an optical fiber loop, as the ringdown “cavity.” Light radiation is coupled into the fiber loop. When the light source is rapidly shutoff, the resultant light rings inside the fiber loop for many round trips. In each round trip, a small fraction of light leaks into a photodetector through a fiber coupler. The rest of the light rings in the fiber experiencing internal fiber transmission losses. The signal intensity observed by the detector follows an exponential decay. The lower are the losses of the light in the fiber, the longer is the decay time constant (ringdown time). This type of fiber ringdown technique, functionally, resembles the standard high reflectivity cavity righdown for absorbance measurements but without the requirements of high reflectivity components.

The fiber ringdown device consists of two identical 2×1 fiber couplers, two sections of fused silica single mode fiber (Corning SMF 28), a temperature controlled diode laser at 1650 nm (the use of the diode laser wavelength is not particularly selected just based on availability of the laser diode in the laboratory) and a photodetector. The quoted tap ratio in the 2-leg end of the fiber couplers is 1: 99. The two 1-leg ends and the two 99% legs of the two couplers are spliced together, respectively, to form a fiber loop. The light from the single mode fiber of the pig-tailed laser diode is coupled into the fiber loop

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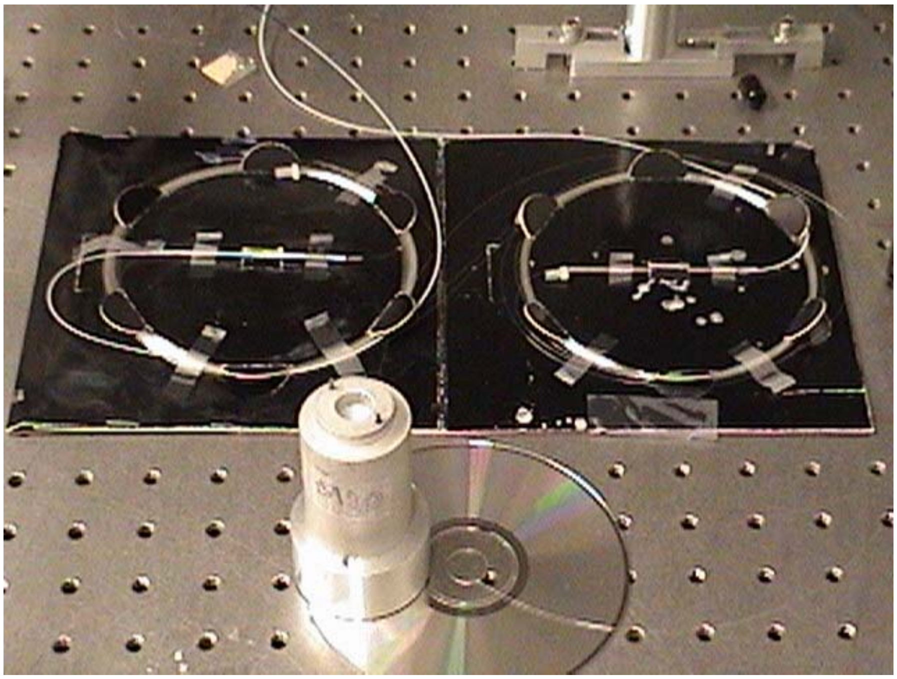
6 Wang, Chuji; Scherrer, Susan T. "Fiber ringdown pressure sensors," Opt. Lett. 29(4), 352 (2004)

7 Wang, Chuji; Scherrer, Susan T. "Fiber loop ringdown for physical sensor development: pressure sensor,"

through the 1% leg with FC/APC fiber connectors, and the 1% leg of the second coupler is coupled to the photodetector. The total length of the loop is 61 meters. The quoted insertion loss of each coupler is less than 0.2 dB. The absorption loss rate of the fiber is 0.3 dB/km at 1550 nm and slightly higher at 1650 nm.

Figure 26. Fiber Ringdown Pressure/force Sensor Demonstrates a Rapid Response and Very Good Repeatability. The applied force is 237 grams, corresponding to ~ 338 psi.



A typical fiber ringdown pressure sensor unit

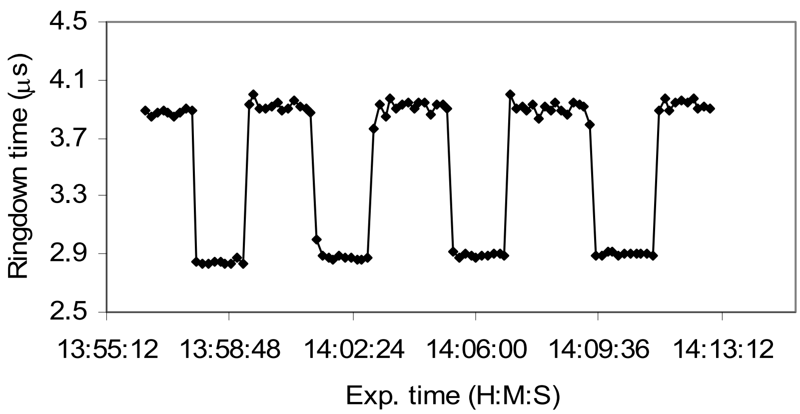
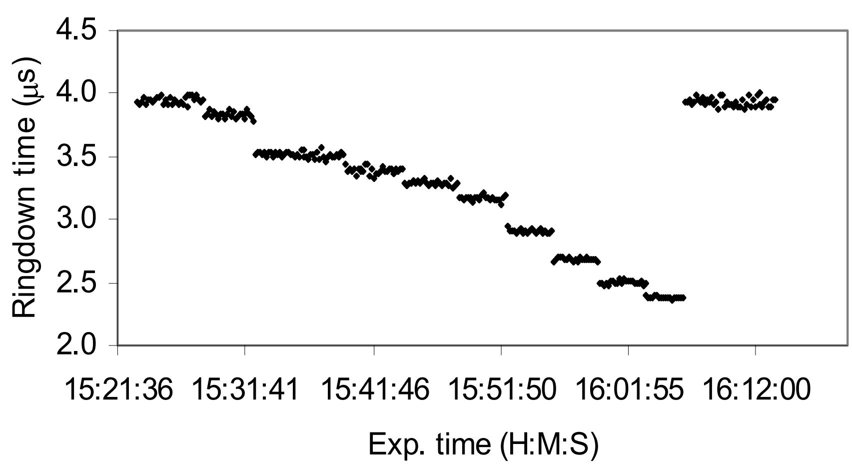


Figure 26 shows the ringdown response to a 237 grams force loaded and unloaded on the pressure sensor. One section the fiber loop lies on the clean surface of the stainless optical table with the fiber jacket removed from this area. A separate piece of fiber, which is independent of the fiber loop but with the same fiber material, is similarly prepared with the fiber jacket removed and placed parallel to the section fiber loop on the optical table. A light aluminum plate (~ 1 gram) of a rectangular shape sits on the top of these two sections of fibers to form a Π shape-platform. The contacted area is the fiber cladding layer, and the contacted length of each section of the fiber to the rectangular aluminum plate is 8 mm. In this way, the real force applied to the sensor is approximately half of the forces loaded on the Π shape-platform. Therefore, when 474 grams force, comprised of six identical aluminum plates, circular in shape and each weighing 79 grams, is loaded on the Π shape-platform, the 237 grams force is applied to the sensor. Since the diameter of the fiber cladding layer is 125 μm, the 237 grams force approximately corresponds to 338 psi pressure, determined using the equation P=F/S. Each of the data points in Figure 26 comes from an average of 100 ringdown events. The curve shows that the fiber ringdown pressure sensor not only has a rapid response to pressure but also shows very good repeatability.

Figure 27 shows a typical testing curve obtained for measured ringdown times vs. applied forces. The applied forces are in the range of 0 - 418 grams, which approximately corresponds to pressures in the range of 0 - 595 psi, also based on the equation P=F/S. The measured ringdown times decrease from 3.94 μs at 0 psi to 2.38 μs at 595 psi. A linear fit of the measured ringdown time vs. force shows a good linearity.

Figure 27. Ringdown Time Responses to Forces Applied on the Sensor. Each distinctive step corresponds to a different applied force. From the left to the right, the applied forces are 0, 40, 79, 158, 198, 237, 281, 339, 378, 418 and 0 grams.



Another issue to be addressed is the relation of detection sensitivity vs. the length of the fiber in contact with the applied force. It is found that for a given fiber ringdown device, the longer the fiber section that is used as the sensor "head," the more sensitive is the sensor. In our experiments, the absolute value of the slope increases from 0.0037 to 0.0072 when the fiber length in the sensor head increases from 8 mm to 16 mm. Similarly, the slope decreases from 0.0037 to 0.0031 when the length decreases from 8 mm to 6 mm. The variation of the slope is approximately proportional to the variation of the fiber length used in the sensor head. This result indicates that sensors could be designed and fabricated with selected areas to yield design-specified detection sensitivities.

Another experiment was conducted to examine the dynamic measuring range of the sensor. It was found that when force was applied to the fiber with the plastic fiber jacket intact, the detection sensitivity decreased. However, the fiber jacket served as a buffer and greatly increases the upper limit of the measuring range. With the same fiber-pressure interaction length, 8 mm, the measurable force was up to 750 grams, or 1068 psi. The force damage threshold was not tested in order to protect the sensor. This test suggests that if the specifically designed sensor head is adopted, e.g., using a protection layer or a buffer layer outside the fiber, FRP sensors will be suitable for pressure sensing in high measuring ranges.

MM&V Tool Box

MSU's efforts in monitoring MM&V technologies and protocols are integrated into SECARB's Most Promising Opportunities and deployment plans. An initial step in this process will be the linking of MM&V technology providers with SECARB's field verification teams in Phase II. The work performed under this task provides the basis for such integration. The focus is upon the MM&V "Tool Box" that is under development in universities, national laboratories and the private sector.

Task 4: Public Involvement

This task addressed public involvement and education mechanisms. The Partnership developed public involvement and education mechanisms that raised awareness of sequestration opportunities in the Southeast and provided interested stakeholders with information about supporting technology development efforts. SECARB activities for this task included:

4.A. Assessment of public involvement options for the region. Augusta Systems reported upon multiple research activities that were implemented to assess the public involvement options in the Southeast region (Deliverables Appendix Document, Volume I, Bookmark 4.A). The assessment entailed the establishment of a focus group; an industry focus group, the development of interviews with environmental nongovernmental organization (NGO), and a review of the history of environmental activities in the region. The research concluded that there are two tiers of stakeholders that can disseminate information on carbon sequestration and would be interested in obtaining informational resources on this topic. The first tier of organization that would receive data in regards to carbon sequestration includes elected officials, environmental non-governmental organizations (NGOs), industry leaders, and regulators. The second tier involves organizations that can provide the general public with information on carbon sequestration, which includes the news media resources.

4.B. Assessment of education options for the region. Augusta reported upon research activities that were implemented to assess the education options for the Southeast region (Deliverables Appendix Document, Volume I, Bookmark 4.B). The assessment entailed the establishment of a focus group; an industry focus group, the development of interviews with environmental NGOs, and a review of the history of environmental activities in the region. The research concluded that there are several educational venues in the region that are suitable for educating stakeholders on the carbon sequestration issue. The educational venues include the SSEB Chairman's Forum, the SSEB Annual Meeting, the Southern Legislative Conference Annual Meeting, and meetings of the SECARB Technical Team and Technology Coalition.

4.C. Public involvement and education mechanisms that raise awareness of sequestration opportunities in the region. Augusta implemented public involvement and educational mechanisms for the Southeast region (Deliverables Appendix Document, Volume I, Bookmark 4.C). The assessment entailed the establishment of a focus group; an industry focus group, the development of interviews with environmental NGOs, and a review of the history of environmental activities in the region. The research concluded that there are fourteen educational options that can be used by stakeholders to disseminate information on carbon sequestration to the general public, which includes industry briefing papers, weblogs, and presentations. Additionally, there are seven stakeholders groups that utilize information on carbon sequestration; including elected officials, environmental NGOs, industry leaders.

4.D. Resource documents identifying outreach sources within the region. Augusta Systems implemented public involvement and educational mechanisms for the Southeast region (Deliverables Appendix Document, Volume I, Bookmark 4.D). The assessment entailed the establishment of a focus group; an industry focus group, the development of interviews with environmental NGOs, and a review of the history of environmental activities in the region. The research concluded that there are fourteen educational options that can be used by stakeholders to disseminate information on carbon sequestration to the general public, which includes industry briefing papers, weblogs, and presentations. Additionally, there are seven stakeholders that present and consume information on carbon sequestration; including elected officials, environmental NGOs, industry leaders.

4.E. Information to interested stakeholders about supporting technology development efforts. Augusta presented information to interested stakeholders supporting technology development efforts for carbon sequestration (Deliverables Appendix Document, Volume I, Bookmark 4.E). First, it was reported that SSEB has partnered with Augusta to incorporate the Carbon Offset Opportunity Program (CO-OP) into its outreach activities. CO-OP is an Internet-based tool that can assist organizations in collaborating to develop projects that offset or reduce GHG emissions, including carbon sequestration projects. Secondly, Augusta in its research activities disseminated information on carbon sequestration at stakeholder meetings and conferences, in addition to providing outreach to various advisory boards.

Task 4 Highlights

As part of its mission, SECARB has a goal to develop public involvement and education mechanisms and plans to raise public awareness of sequestration opportunities in the region and provide interested stakeholders with information about technology deployment efforts. Through the efforts of the SECARB team, SECARB has worked to advance this goal and the overall mission during the first phase of the RCSP initiative. As a result of the unique structure of the SSEB, SECARB was well positioned to obtain input from a broad cross-section of stakeholders and developed public involvement and education mechanisms and associated multi-year action plans to assist in the wide-scale deployment of carbon sequestration technologies and approaches.

To meet the public outreach and education goals of SECARB, the Partnership assessed public perception regarding the SECARB program through the undertaking of in-depth research. This research assisted in the development of the formal action plans for public outreach and education required for successful completion of the Phase I activities.

To serve the needs of public perception assessment, the SECARB team utilized various communications to engage and inform opinion leaders and stakeholders in the Southeast and beyond on SECARB and its goals. Information about SECARB was disseminated through various communications and events, including presentations at the North American Power Markets Conference, the Energy and Mineral Law Foundation Winter Meeting, and the West Virginia Environmental Academy; an article in *Coal Leader*; the announcement of the incorporation of the Carbon Offset Opportunity Program into SECARB's outreach efforts and meetings of the SECARB Technical Team and Technology Coalition, among others.

In addition, the SECARB team continued its assessment of public perceptions to ascertain knowledge of and interest in carbon sequestration to facilitate and structure on-going education and outreach efforts. These efforts built upon the successful industry focus group discussion during the first year of SECARB activities. The focus was on the unique environmental histories of the states in the SECARB region and the public perceptions of carbon sequestration among environmental non-governmental organizations in the region.

Specifically, these assessments involved survey research methods conducted by RMS Strategies and The Phillips Group, with the assistance of Augusta Systems and SSEB. Opinions of environmental non-governmental organization stakeholders were studied for the purposes of outreach message development to governmental representatives from states in the SECARB region. Understanding the unique environmental history of each state is important as it pertains to project permitting and historical public reaction to project development, for instance. Activities included completion of the report on findings from the industry focus group and development and implementation of the survey research efforts involving environmental non-governmental organization stakeholders and governmental representatives from states in the SECARB region.

SECARB Integrated Outreach Strategy

The Partnership team implemented the integrated outreach strategy developed during the first year of activities. This strategy served as an initial action plan for the Phase I effort.

The objective of the SECARB Integrated Outreach Strategy is to implement an outreach and education program that connects the value of carbon sequestration technologies among multiple constituencies. The program incorporates both internal, which includes SECARB Technical Team and Technology Coalition partners, and external components with strategies targeted to respective audiences and their needs. It helped to create awareness and comprehension of the purpose of the SECARB as outlined by the objectives of DOE and NETL. It advanced RCSPs through the distribution of ongoing analysis and findings relative to the activities of SECARB initiatives. As a result, the application of carbon sequestration technologies are being accepted as an economically and environmentally sound energy technology and approach.

The SECARB Integrated Outreach Strategy consists of four key elements. These include determination of stakeholders and needs; establishment of outreach goals; determination of outreach strategies; and initiation of outreach activities and on-going evaluation. The Strategy is further detailed below.

Determination of Stakeholders and Needs

To initiate the outreach program, the SECARB outreach team identified the appropriate SECARB partners and other stakeholders and moved forward to determine the needs of these stakeholders with reference to education and outreach through the use of communications and survey research activities. The SECARB partners included, among others, the SECARB Technical Team members, the SECARB Technology Coalition members, DOE and others as defined by the SECARB leadership. In addition, the other SECARB stakeholders included SECARB regional organizations from industry, environmental non-governmental organizations, the public, other special interest groups, academic and research institutions, government agencies and others, including stakeholders from beyond the SECARB region.

Establishment of Outreach Goals

The SECARB outreach team also worked to set outreach goals focused on both SECARB partners and external SECARB stakeholders. These goals support the objectives of DOE, NETL and SECARB in generating understanding and support for carbon sequestration technologies among stakeholders. These goals are based upon four factors, as follows:

- Background research and survey research activity analysis;
- Existing environmental history that could drive awareness, education and attitude needs of audience;
- Technology validation needs; and
- Potential barriers to acceptance of carbon sequestration technologies and approaches.

Determination of Outreach Strategies

Utilizing the above steps, SECARB determined outreach strategies. The outreach strategies developed the infrastructure, mechanisms and implementation methodologies aligned with DOE, NETL and SECARB in terms of overall objectives and objectives of the Integrated Outreach Strategy. The outreach strategies, which will be targeted at both SECARB partners and other SECARB stakeholders, include focuses on:

- Stakeholder Prioritization;
- Message Development;
- Identity Development;
- Technology and Approach Concept Training;
- Outreach Infrastructure Development (possibilities include SECARB Web page, e-mail lists, newsletter, letters, resource book, forums, brochures, fact sheets, maps, charts, background papers, SECARB fact sheets, background papers, maps, etc.); and
- Outreach Timeline Development (for outreach on findings, announcements, achievements, ongoing activities, results, etc.).

Under this element, SECARB developed the Action Plan for Public Involvement, Education and Acceptance called for by Subtask 6.5 of the SECARB scope of work. As part of this overall plan, SECARB has embraced utilization of the NETL-supported Carbon Offset Opportunity Program as a tool to assist in facilitating collaborative carbon sequestration activities in the SECARB region.

Formal Initiation of Outreach and On-going Evaluation

This initiation of outreach and on-going evaluation centers on the development and refinement of the Action Plan for Public Involvement, Education and Acceptance called for by Subtask 6.5 of the SECARB proposal. This element includes the action plan delivery and measurement of the infrastructure and strategies for SECARB outreach and education.

Stakeholder Needs Analysis: In-Depth Survey Research Activities

As noted, the determination of stakeholder outreach and education needs element of the effort was conducted. These activities focused on (1) SECARB Regional Perceptions of Carbon Sequestration; and (2) SECARB Region Environmental History Research. Details on these areas follow.

SECARB Regional Perceptions of Carbon Sequestration

The objective of the SECARB regional perceptions of carbon sequestration research effort was to determine and evaluate the attitudes and perceptions of key opinion leaders, including most notably leaders of industry and environmental non-government organizations regarding carbon sequestration issues. The primary goals of the study were to assess the awareness and understanding of carbon sequestration; identify any barriers to the carbon sequestration effort; and determine effective messages among the stakeholders. Thus, the results of this research directed the outreach and education efforts for SECARB.

With the SSEB Annual Meeting in September 2004 providing a suitable platform for an industry focus group session in Richmond, Virginia, RMS Strategies led the focus group activities and conducted the planning and structuring of these activities with the assistance of Augusta Systems and the SSEB. RMS Strategies delivered a program that elicited responses to a host of question areas, including:

- General environmental perceptions;
- Climate change perceptions;
- Overall awareness of carbon sequestration efforts; and
- Messaging.

To further ascertain perceptions from other SECARB constituencies, including national and regional environmental nongovernmental organizations, a list of similar questions was posed to a select group of identified SECARB environmental non-governmental organization stakeholders by RMS Strategies, with assistance from Augusta Systems and the SSEB, through a telephone-based, in-depth interview process. A report of findings from these discussions was completed in the third quarter of 2005.

SECARB Region Environmental History

To support efforts to ascertain the appropriate outreach strategies and mechanisms that should be employed to assist with wide-scale carbon sequestration deployment in the SECARB region, The Phillips Group undertook a research effort to determine the environmental history of states within the SECARB region. Due to the unique structure of the Southern States Energy Board, as an interstate compact, the Phillips Group was able to directly contact agency professionals in all the SECARB states. The research, taking the form of a telephone interview with state energy and environmental officials, assisted the Partnership with its outreach efforts. Through this survey, SECARB gained knowledge of the environmental issues unique to each state in the SECARB region to better understand how these issues may relate to regional and national carbon sequestration efforts. A report of findings from these discussions was submitted to DOE/NETL in the third quarter of FY2005.

Meetings and Presentations

SECARB project team members participated in numerous events over the two-year program period. The purpose was to present the SECARB activities and gain support for, and recognition to, the DOE/NETL Regional Carbon Sequestration Partnership program. Such presentations/events include, but are not limited to, those listed below.

- NETL Regional Carbon Sequestration Partnership kick-off meeting in Pittsburgh, Pennsylvania, November 3-4, 2003
- SECARB's first meeting of the Technical Team and Technology Coalition in Atlanta, Georgia, January 14-15, 2004
- SSEB Associate Members Meeting in Washington, DC, February 23, 2004
    - SECARB recognition by former Governor Bob Wise of West Virginia, who served as SSEB's Chairman at that time
- American Chemical Society Annual Meeting in Anaheim, California, March 31, 2004
- North Carolina State Mercury/ CO_2 workshop April 19-21, 2004
- Third Carbon Sequestration Partnership meeting, May 2-5, 2004
- NETL Workshop, May 6, 2004
- Second Technical Team/Technology Coalition quarterly meeting in conjunction with the SSEB Chairman's Forum on Carbon Management, May 19-21, 2004
- Regional Environmental Impact Statement public meeting sponsored by NETL in Norcross, Georgia, June 2, 2004
- CO_2 conference at the University of Georgia, June 10-11, 2004
- COOP Meeting, Charleston, West Virginia, on July 13, 2004
- Southern States Energy Board Briefing to Legislative Members, Little Rock, Arkansas, on August 14, 2004
- Southern States Energy Board Associate Members and Utility Advisory Committee Meeting, Richmond, Virginia, on September 11, 2004
- Southern States Energy Board 44th Annual Meeting, Richmond, Virginia, on September 13, 2004
- SECARB Focus Group Meeting, Richmond, Virginia, on September 13, 2004
- "Geological Working Group Meeting" in Houston, Texas, on October 20, 2004
- "MIT Carbon Sequestration Forum V: Overcoming Barriers to CCS Implementation" in Cambridge, Massachusetts, on November 2-3, 2004
- NETL "Regional Carbon Sequestration Partnerships Annual Program Review Meeting" in Pittsburgh, Pennsylvania, on November 16-17, 2004
- SECARB Technical Team/Technology Coalition Meeting on Geologic Characterization, December 17, 2004
- SECARB Technical Team/Technology Coalition Meeting, January, 20, 2005
- SECARB Partnership Status Briefing to Southern Company Senior Management, January 2005

- "Southern States Energy Board Associate Members Meeting", February 28, 2005
- SECARB Presentation to Duke Energy in Charlotte, North Carolina, April 14, 2005
- SECARB Presentation to SCANA Energy in Columbia, South Carolina, April 15, 2005
- 3rd Annual West Virginia Leadership Conference in Charleston, West Virginia, April 27, 2005
- Carbon Sequestration Leadership Forum in Alexandria, Virginia, May 2, 2005
- 4th Annual Carbon Sequestration Workshop in Alexandria, Virginia, May 5, 2005
- Eastern Coal Council Meeting in Kingsport, Tennessee, May 24, 2005
- The Energy Council's "2005 State and Provincial Trends in Energy and the Environment Conference" in St. John's, New Foundland, June 25, 2005
- Briefing to South Carolina state officials and to SCANA in Columbia, South Carolina, July 20-21, 2005
- Southern States Energy Board Briefing to Legislative Members in Mobile, Alabama, July 30, 2005
- Southern States Energy Board Associate Members Meeting in Mobile, Alabama, July 30, 2005
- Southern States Energy Board 45th Annual Meeting in Greensboro, Georgia, August 27-29, 2005

Task 5: Identify Most Promising Capture Sequestration and Transportation Options

SECARB has identified the most promising regional options for CO2 capture, transport and storage through characterization and matching of the region's sources and sinks. The two-year investigation has enabled SECARB to focus on the most promising geologic field options that promote a framework and infrastructure necessary for the validation and deployment of carbon sequestration technologies. Three technology validation studies, with four field locations, have emerged as the most promising capture, sequestration and transport options in the region.

5.A. Plan for identifying promising capture options. SECARB reviewed and analyzed information from the perspective of technical feasibility, safety, estimated cost, perceived public acceptability, CO_2 reduction potential, and environmental efficacy in determining which field verification options would be the most promising in the region. The Electric Power Research Institute (EPRI) has extensive involvement in carbon capture technology planning and investigation. EPRI is leading the SECARB effort (Deliverables Appendix Document, Volume I, Bookmark 5.A).

5.B. Summarize most promising capture options. The current state of CO2 capture technologies was reviewed in order to provide input into the design of a CO2 capture and storage test facility. First, an overview of the three major approaches to CO2 capture was provided, noting that only one of these options, postcombustion capture, is compatible with the design criteria for the test facility.

Second, current research efforts for post-combustion capture were reviewed, giving examples of technologies that may be appropriate for the test facility. Third, data on existing test facilities worldwide was summarized, in order to learn from previous experience. Lastly, the latest set of peer-reviewed papers on CO2 capture technology from the Seventh International Conference on Greenhouse Gas Control Technologies, GHGT-7, were presented to help update the information in the report (Deliverables Appendix Document, Volume I, Bookmark 5.B). Field Test Opportunity 3 (below) is the result of an extensive collaboration with EPRI who plans to identify a Test Center for the purpose of capturing CO2 from an existing coal fired power plant.

5.C. Plan for identifying promising transportation options. This subtask assessed transport requirements for matching sources and sinks within the region, addressing the cost and feasibility of the transport mode. Massachusetts Institute of Technology (MIT) developed a work plan and conducted an assessment of CO2 transport systems in the Southern region (Deliverables Appendix Document, Volume I, Bookmark 5.C). The plan matched sinks with potential sources utilizing optimization models.

5.D. Summarize most promising transportation options. MIT developed prototype transportation options for the eastern counties of Texas to test its optimization model (Deliverables Appendix Document, Volume II, Bookmark 5.D). In summary, MIT determined that transportation options for existing sources with various sinks favored matching with “stacked storage formations” where CO2 could be utilized for enhance oil recovery (EOR) initially, followed by storage in deep saline formations. The reason for this is the ability to off-set infrastructure costs with revenue from CO2-EOR. Field Opportunity 1: Gulf Coast Stacked Storage is a most promising field verification option that incorporates CO2-EOR reservoirs stacked on deep saline reservoirs.

5.E. Plan for identifying most promising geologic formations and options for best utilizing them for CO2 storage. SECARB developed a geologic sink activity analysis plan for the region (Deliverables Appendix Document, Volume I, Bookmark 5.E). Selection criteria were developed to aid in the identification of the most promising geologic formations and in selecting options that would be most promising for CO2 storage.

5.F. Plan for identifying most promising terrestrial storage options. Winrock International is a leader in terrestrial ecosystem assessments and in calculating the potential of various terrestrial systems to store carbon. A plan for compiling terrestrial data was developed by Winrock and also utilized by Texas and Virginia (Deliverables Appendix Document, Volume II, Bookmark 5.F).

5.G. Summary of most promising geologic and terrestrial options for CO2 storage. SECARB established a geologic working group to compile information, review findings and identify the most promising geologic options in the region. Augusta Systems summarized the geologic information in its report for SECARB (Deliverables Appendix Document, Volume I, Bookmark 5.G1). Summary information on the most promising terrestrial options for CO2 storage was provided by Winrock, University of Texas and Virginia Tech (Deliverables Appendix Document, Bookmark 5.G2 in Volume I and Bookmarks 5.G3 and 5.G4 in Volume II).

5.H. Plan for identifying promising commercial use options. DIAL developed a plan for identifying new commercial usage opportunities (including expansion of existing usage) for CO2 within the region (Deliverables Appendix Document, Volume II, Bookmark 5.H). Potential commercial use options will include enhanced oil recovery in Texas, Louisiana, and Mississippi; and enhanced coal bed methane (ECBM) recovery with CO2 is a potential commercial use in Alabama, Mississippi, and Virginia. Capture of CO2 for use as a commercial gas has limited opportunities in the region.

5.I. Map showing links between sources and most promising commercial users. MIT developed models for optimizing the matching of sources and sinks in the SECARB region. Results of the source and sink matching analysis, as performed in the eastern counties of Texas and including CO2-EOR commercial users, is presented in Figure ES-4, a map of the data results (Deliverables Appendix Document, Volume II, Bookmark 5.I).

Task 5 Highlights

SECARB has identified the most promising regional options for CO_2 capture, transport and storage through rigorous characterization of the region's sources and sinks. The two-year investigation has enabled SECARB to focus on the most promising geologic field options that promote a framework and infrastructure necessary for the validation and deployment of carbon sequestration technologies (see details below).

Field Test Opportunity 1: Gulf Coast Stacked Storage

This most promising opportunity leverages the economic benefits of enhanced oil recovery (EOR) to help offset the cost of infrastructure needed to capture, transport and store CO2 in geologic formations. The Gulf Coast has numerous opportunities for CO2 EOR, with depleted reservoirs that are stacked with saline aquifers at great depths. A thick sedimentary wedge of Tertiary and Quaternary rocks up to 12,000 ft (3,658m) defines the Gulf Coast subregion, the onshore area of which is 154,440 mi^2 (400,000 km^2). Internal structure and properties of the Gulf Coast wedge are well known because of extensive exploration for end production of hydrocarbons. Examination of regional maps and cross-section sets (Dodge and Posey, 1981; Galloway, 1982; Hosman, 1996) shows the maximum depth (where detailed regional data are available) is 14,000 ft (4,000 km); deeper potential exists but was not assessed. Fresh and brackish water protected as USDW extends relatively deep (2,000 to 3,500 ft [610 to 1067m]) in this region (Arthur and Taylor, 1990; LBG Guyton Associates, 2003, Brackish groundwater manual for Texas; Hovorka and others, 2004b). In order to give adequate protection to USDW, the SECARB team assumes potential storage can begin at 4,000 ft (1,219m), which will allow the injection zone to be overlain by several thick, extensive shale-seal barriers to migration and a buffer of permeable sandstones to assure high permanence of storage. Sandstone porosity and permeability are high in the relatively young sediments of the Gulf Coast wedge, averaging 25% to 35% and .5 to 3 darcys. With respect to the national picture, the entire region is a target, so an average net sand value of 23% was used, based upon the evaluation of type logs (Dodge and Posey, 1981). Using lower Gulf Coast area of 240,000 km^2 with a stratigraphic thickness of 2.4 Km and the 23% porosity, Gulf Coast Carbon Center (GCCC) calculated total brine-filled subsurface porosity capacity of 42,000 km^3. Injection simulation in typical, geologically heterogeneous Gulf Coast sandstones (Hovorka and others, 2004a) has shown that capacity is a complex of multiple variables, including dissolution, two-phase trapping, buoyancy trapping, and complex migration paths. Additional experimentation, followed by modeling, is needed for realistic and defensible capacity assessment to be done. However, 1% of the large subsurface volume could hold 428 years of the region's entire current CO_2 production, which motivates continued research.

Half the generating capacity of the subregion is from coal and lignite-fired power plants; the other half is gas fired, providing a diverse suite of options for capture. Both refiners (Chevron Texaco and BP) and utilities (Entergy and NRG) have joined the GCCC and are actively engaged in seeking a viable carbon capture and storage project (CCS) in a geologic setting with an economic driver. Without an effective program to capture and store CO_2 emissions from the Gulf Coast, the national GHG intensity goals will be difficult to reach.

CO_2-EOR could generate significant potential revenue streams to offset or completely cover costs of transportation infrastructure. Stakeholders, CO_2 emitters, operators and communities, have shown strong interest in taking action to prolong production at fields with declining production through CO_2-EOR. GCCC, through collaboration and academic funding, completed an assessment of geologic storage options in the Gulf Coast region. GCCC inventoried 0.4 billion tons of CO_2 produced annually from 316 stationary sources in the region. Capture of CO_2 from these sources could supply a 680-mi (1,095-km) pipeline infrastructure that links the Gulf Coast region in a network extending from Alabama to Mexico. This area comprises 767 oil and natural gas reservoirs that could be used first for EOR and then for large-volume, long-term storage of CO_2 in nonproductive formations below the reservoir interval. Modest investments could provide economic incentives for the oil and gas industry to support expanded EOR programs that will yield potential storage sites. Within Texas alone, GCCC estimates that, outside the traditional area of CO_2-EOR in the Permian Basin, an additional 5.7 billion barrels (Bbbl) of oil could be produced by using CO_2-EOR. By way of comparison, annual U.S. oil production is currently 3.2 Bbbl. This EOR activity could also lead to the storage of more than 700 million tons (0.7 gigaton) of CO_2—only a small part of the positive impact. The true prize will be that EOR could enable construction of a CO_2 pipeline infrastructure that could allow cost-effective storage of Gulf Coast power plant, refinery, and chemical plant emissions from fossil-fuel combustion for the next 50 years or more.

Field Test Opportunity 2: Coal Seam Sequestration

The Black Warrior Basin and adjacent parts of the Appalachian thrust belt contain a diverse assemblage of potential carbon sinks, including coal, mature oil and gas reservoirs, and saline aquifers (Pashin and Payton, in review). Among these potential sinks, coal is especially promising because of the potential to sequester large volumes of greenhouse gas while enhancing CBM production (Pashin et al., 2001, 2004). Two coal-fired power plants adjacent to the Black Warrior coal bed methane fields emit more than 31 megatons of CO_2 a year, and the proximity of these plants to the CBM fields makes validation of sequestration and ECBM potential a major priority. Additional capacity exists in CBM reservoirs in the Appalachian thrust belt, but this capacity has yet to be assessed. These reservoirs are close to a third coal-fired power plant that emits nearly 14 megatons of CO_2 annually, thus the potential of coal in the Appalachian thrust belt of Alabama will be assessed during the Phase II program.

Several coal-fired electrical power generation facilities operate in the region surrounding the proposed Central Appalachian pilot, which could provide a large source of CO_2 that, if not captured for sequestration, would be discharged to the atmosphere. The coal fields surrounding the generation facilities provide sequestration sinks for captured CO_2, the extent of which will be addressed in the SECARB project. An extensive natural gas pipeline infrastructure exists in the region, which provides pipeline rights-of-way to transport CO_2 from the facilities to injection locations within the coal fields.

In the Black Warrior coal bed methane fields, the storage capacity of coal locally exceeds 2 MMscm/acre, and the amount of gas left in place after primary CBM recovery is estimated to exceed 0.4 MMscm/acre in some areas (Pashin et al., 2004). Coal in the Black Warrior Basin may be used to sequester up to 1.2 Tscm of CO_2, which is equivalent to 35 years of CO_2 emissions from nearby coal-fired power plants at current rates (Pashin et al., 2001). Through ECBM, more than 14 MMscm of CH_4 may be recoverable from the established CBM fields in the Black Warrior basin, which could prolong the life of the CBM reservoirs substantially and result in a 20% expansion of CBM reserves in the basin (Pashin et al., 2004).

The area identified in the Central Appalachian Basin for carbon sequestration opportunities in coal seams encompasses portions of southwestern Virginia (Buchanan, Dickenson, and Wise Counties, southern West Virginia (Fayette, McDowell, Raleigh, and Wyoming Counties), and counties in eastern Kentucky (Harlan, Letcher, and Pike Counties). A total storage capacity of 0.86 Tscm has been estimated for the Middle to Lower Lee and Pocahontas Formations in Buchanan and Dickenson Counties, Virginia (Karmis, 2005). The technically feasible storage capacity estimate for these two counties, excluding mineable areas and areas not yet developed for CBM production, is 0.31 Tscm. CO_2 sequestration has the associated potential to recover an incremental 22.7 Bscm of enhanced coal bed methane. This region of Appalachia has been densely drilled for both conventional and CBM reservoirs; therefore, an extensive and mature natural gas pipeline infrastructure exists over the majority of the area defined for carbon sequestration potential. In addition to CO_2 sequestration, coal can be used as a natural separator for flue gas and may also sequester extremely large quantities of SO_X and NO_X emissions (Chickatamarla and Bustin, 2003). If proven, this breakthrough concept could revolutionize the possibilities for cost-effective CO_2 capture. Hence, coal may play a significant role in sequestering the full range of acid gases emitted by coal-fired power plants and may be pivotal to the development of novel technologies for acid gas mitigation. The proposed injection tests for CO_2 constitute an early step in realizing the acid-gas sequestration potential of coal. Modeling efforts during this study also will explore the possibility of sequestering multiple acid gases in coal. Advanced Resources work on Burlington Resources' CO_2-ECBM pilot in the San Juan Basin demonstrates the practicability of CO_2 storage in coal seams as well as the value-added benefits of such a project. The prospect of enhancing CBM production while proving that carbon sequestration in coal seams is feasible in the southeastern United States will represent significant progress in limiting GHGs in our region.

Field Test Opportunity 3: Mississippi Salt Basin

The site is located along the southern boundary of the Mississippi Interior Salt Dome Province above the most significant structure of the local geology, the Wiggins Arch. The Wiggins Arch separates the Mississippi Salt Basin from the Gulf Coast Salt Basin. The Mississippi Salt Basin subsurface in the region is characterized by numerous salt related structures especially salt domes. Other salt related structures in the area include ridges and anticlines. These structures developed as a result of ascension of the Jurassic-age Luann Salt caused by sediment loading. South of the site area, sediments dip into the Gulf of Mexico where they are also punctuated by salt piercement domes of Jurassic-age Louann Salt. The site is located on Quaternary-age sediments. The stratigraphic section in the area (above the Paleozoic-age basement) contains over 20,000 feet of Jurassic through Tertiary-age sediments. The stratigraphic section in the area thins northward and thickens southward toward the Gulf Coast, except over salt structures and basement structures. Regional dip is to the southwest. Tertiary-age lithology consists of sand with interbedded shale and minor amounts of limestone. The Createceous-age lithologies consist of interbedded sandstone, shale, and limestone with minor amounts of anhydrate. The Jurassic-age lithologies include salt, anhydrite, limestone, dolomite and sandstone. Deep confined aquifers for the site area include sandstones of the Cretaceous-age Eutaw, Tuscaloosa, Dantzler, Paluxy and Sligo formations and the Jurassic-age Cotton Valley and Norphlet formations. Where these sandstones are in fault blocks and truncate at the flanks of salt domes, some oil and gas may be trapped within these larger aquifer systems. These sandstone and carbonate aquifers and their associated confining units are part of the Gulf Coast Cenozoic to Mesozoic-age mixed siliciclastic carbonate wedge that attains a maximum thickness of over 23,000 feet and extends from northern Mississippi to deep into the Gulf of Mexico. This wedge of sediments and rocks thickens northwestward from the site area into the Mississippi Interior Salt Basin, thins over the Wiggens Arch, and then thickens again into the Gulf of Mexico. The Cretaceous-age Eutaw Formation reservoir is a marine shelf sandstone found at 8,000 feet near the major salt domes in the site area. Eutaw reservoir porosities range up to 30% with permeabilities up to 500 millidarcies. Eutaw Formation thickness is 500 feet containing 50% sandstone. The Cretaceous-age Tuscaloosa and Lower Tuscaloosa, Dantzler, and Paluxy reservoirs consist of fluvio-deltaic sandstone and are found at depths of 9,000 to 11,000 feet. Reservoir porosities range up to 30% with permeabilities as high as 1,000 millidarcies. The combined Tuscaloosa and Lower Tucscaloosa, Dantzler, and Paluxy formations are 3,000 thick and consist of 50% sandstone. The Sligo/Hosston reservoir is composed of deltaic and shelf deposits and is found at depths of 12,000 to 14,000 feet. Reservoir porosities range up to 15% with permeabilities up to 15 millidarcies. The combined Sligo/Hosston Formation thickness is 2,500 feet consisting of 65% sandstone. The Jurassic-age Cotton Valley Formation is a deltaic to slope-fan deposit found at 15,000 feet of depth. Cotton Valley reservoir porosity ranges up to 15% with permeabilities up to 15 millidarcies. Cotton Valley Formation thickness is 1,500 feet containing 90% sandstone. The Jurassic-age Norphlet Formation is an eolian deposit at a depth of 22,000 feet. Reservoir porosities range up to 12% with permeabilities of less than 5 millidarcies with a thickness of 200 feet (Kuuskraa, 2004).

Task 6: Prepare Action Plans for Implementation and Technology Validation Activity

Under Task 6, the SECARB team developed an integrated approach to implementing the most promising field validation activities in the region.

Action Plans have been prepared to implement a framework leading to small-scale regional technology validation field tests. SECARB considered cost-effective approaches that provide flexibility for assessing multiple candidate technology options. Action Plans consist of three field verification plans and supporting plans in education/outreach, permitting, regulatory and accounting frameworks.

6.A. Action Plans for Capture, Transport and Sequestration Options. Action Plans have been developed for field validation of three diverse technology options (Deliverables Appendix Document, Volume II, Bookmarks 6.A1 and 6.A2). The Action Plans emphasize technology validation related to geologic sequestration. All field validation options are based upon Action Plans that will obtain CO2 from existing sources. The transport option is designed to take advantage of existing CO2 pipeline infrastructure, where possible, with truck transport for the final miles between the CO2 source and sequestration site. Field Test 3 is designed to facilitate the future prospect of post-combustion capture and separation of CO2 at an existing power plant immediately adjacent to a deep saline storage reservoir.

6.B. Action Plan for Implementation of New/Expanded Usage Opportunities. The most promising opportunities identified in the SECARB region include reforestation and changes in agricultural practices, mineralization, enhanced oil recovery and enhanced coal bed methane recovery (Deliverables

Appendix Document, Volume II, Bookmark 6.B). The Action Plan for Field Test 1 focuses on expanded usage opportunities for CO2 enhanced oil recovery. The Action Plan for Field Test 2 focuses on expanded usage opportunities for CO2 enhanced coal bed methane recovery.

6.C. Small Scale Regional Field Test Plan for Technology Development. Action Plans have been developed for field validation of three diverse technology options (Deliverables Appendix Document, Volume II, Bookmark 6.C). The three SECARB field test plans are all focused on geologic sequestration. While promising opportunities for terrestrial sequestration and mineralization exist within the region, the most promising opportunities are related to geologic sequestration with opportunities for offsetting costs. Field Test 1 builds on opportunities that exist for CO2 enhance oil recovery; Field Test 2 builds on opportunities that exist for CO2 enhance coal bed methane recovery. Any technology deployment that is aided by these small scale regional tests will provide benefits in commercial applications by reducing the cost of CO2 transport and injection technology. Field Test 3 is focused upon geologic sequestration opportunities in close proximity to existing coal fired power plants and is operating in parallel to research by EPRI on post-combustion capture and separation.

6.D. Stakeholder Involvement and Outreach Action Plans. SECARB developed an Integrated Outreach Strategy as the action plan for stakeholder involvement. The objective of the strategy was to implement an outreach program that connects the value of carbon sequestration technologies among multiple constituencies (Deliverables Appendix Document, Volume I, Bookmark 6.D). The Integrated Outreach Strategy consists of four elements – determination of stakeholders and needs; establishment of outreach goals; determination of outreach strategies; and initiation of outreach activities and on-going evaluation.

6.E. Information Dissemination and Education Action Plans. SECARB initiated an early implementation of its information dissemination and education action plans (Deliverables Appendix Document, Volume I, Bookmark 6.E1). SECARB prepared power point presentations, poster presentations and information sheets for the regional partnership. A listing of major meetings and presentations highlights the diversity of the information dissemination and education actions conducted by SECARB (Deliverables Appendix Document, Volume II, Bookmark 6.E2). Additionally, SSEB maintains a website (www.secarbon.com) that is linked to NETL and other carbon sequestration sites.

6.F. List of Potential Issues and Perceptions that Concern Stakeholders, along with Prepared Responses to Such Issues and Perceptions. An analysis of concerns and perceptions by the SECARB team led to the development of key message points noted (Deliverables Appendix Document, Volume I, Bookmark 6.F1). As part of the activities of the NETL

Outreach Working Group that includes all regional partnerships, a list of questions and answers was developed in order to provide a consistent message to all stakeholders including the general public. SECARB participated in the development and review of a series of questions and answers. The final version of a short questions and answer reference sheet (Deliverables Appendix Document, Volume I, Bookmark 6.F2) is available for outreach and education activities.

6.G. Action Plans for Removing Potential Barriers to Stakeholder Acceptance of Promising Options. The objective of SECARB's research into stakeholder acceptance was to determine and evaluate the attitudes, perceptions and concerns of key stakeholders(Deliverables Appendix Document, Volume I, Bookmark 6.G). The primary goals of the research were to assess awareness and understanding of carbon sequestration and identify any possible barriers or challenges to carbon sequestration. As noted previously, key message points were developed and frequently asked questions addressed in order to assist in removing barriers to stakeholder acceptance.

6.H. Safety, Regulatory and Permitting Action Plans. Augusta Systems developed action plans for Regulatory, Safety, Permitting and Accounting Frameworks (Deliverables Appendix Document, Volume II, Bookmark 6.H). The Action Plans focus on forming a regulatory working group; assessing the safety, regulatory and permitting landscape; providing assistance to field teams doing technology validation; facilitating outreach/education with safety, regulatory and permitting information; and preparing model guidelines during field validation. In addition, SECARB worked with and supported regulatory activities under the direction of the Interstate Oil and Gas Compact Commission (IOGCC).

6.I. Accounting Framework Action Plans. Augusta Systems developed action plans for Regulatory, Safety, Permitting and Accounting Frameworks (Deliverables Appendix Document, Volume II, Bookmark 6.I). The Action Plans focus on forming an accounting framework working group; assessing the CO2 accounting and verification landscape; providing assistance to field teams doing technology validation; facilitating outreach/education with CO2 accounting and market/trading information; and preparing model guidelines during field validation.

6.J. Early Implementation of Safety, Regulatory and Permitting Action Plans, where possible. A number of aspects of safety, regulatory and permitting activities were candidates for early implementation. SECARB initiated Early Action Plan Activities as part of its Phase I activities (Deliverables Appendix Document, Volume II, Bookmark 6.J).

6-K Early Implementation of Accounting Framework Action Plans, where possible, Action Plans for Capture, Transportation, and Storage. Some of the accounting framework activities were candidates for early implementation.

SECARB initiated Early Action Plan Activities as part of its Phase I activities (Deliverables Appendix Document, Volume II, Bookmarks 6.K1 and 6.K2).

Task 6 Highlights

As part of SECARB's Action Plans, the team will continue to refine Phase I concepts and will begin to validate, through field testing, sequestration technologies and corresponding infrastructure approaches related to regulatory, permitting, and outreach. The multi-partner collaborations that developed during Phase I will continue in Phase II.

SECARB's Action Plans embrace three diverse field tests. Each field test can be broken down into five activities: project definition, design, implementation, operations, and closeout/reporting.

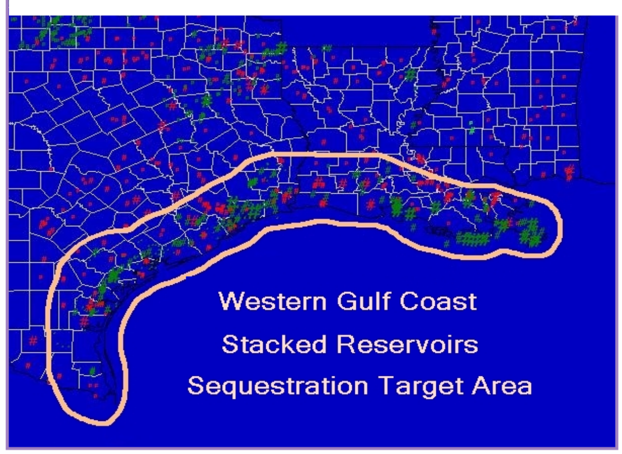
Field Test 1 (FT1): Gulf Coast Stacked Storage Action Plan

The project focuses on oil and gas reservoirs and brine formations to demonstrate advanced methods of CO_2 injection and monitoring for EOR and long-term geologic storage. Because of the large number of potential EOR projects as well as the large number of saline reservoirs, the Gulf Coast is the area of focus for this field test. Figure 28 shows the target area.

FT1 Project Definition

This field test is designed to evaluate the potential for injecting CO_2 into multiple horizons, coupling an EOR effort to provide an economic benefit to the project with sequestration efforts in saline reservoirs "stacked" in close proximity.

Figure 28. Target Area for the Gulf Coast Stacked Storage Project



Each field under evaluation will have an initial reservoir characterization completed, and a preliminary CO_2 injection simulation will be performed. Candidate fields will be narrowed to one site for the field test. Field-wide simulation will be performed for the amount of CO_2 to be injected, and the models recalibrated for any changing reservoir parameters. As FT1 goes into full field injection, the simulation model will be validated and updated as necessary through injection and post injection phases, with a final summary on how accurately the simulation predicts CO_2 injection flow and subsequent oil volumes produced.

FT1 Design

The Gulf Coast team will determine preinjection baseline characterization of CO_2 concentrations that are considered normal. Subsurface characteristics of oil and brine reservoirs also must be determined prior to drilling in order that fluid changes are verified at depth after injection. Specific reservoir characteristics, such as structural dip, depositional stratigraphy and internal fluid type with specific temperature and pressures will be determined. Technical design of the pilot CO_2 injection project will occur over the first two years of the project. The design will focus on assessing an optimal operating oil-field site for both oil reservoir injection and brine injection over time.

FT1 Implementation

The field team will reuse existing infrastructure (road, well, and well pads) as much as possible to minimize environmental impact and reduce cost. New surface installations will be minor and include one or two new wells, most likely placed on existing pads, and an array of low-impact, surface monitoring stations with small cement pads or markers for repeat surface surveys. SECARB will work with regional experts to ensure that the engineering is excellent and all regulatory and health and safety requirements are met.

Observational wells will be installed to observe CO_2 concentration changes and associated pressure and temperature variations during injection. A critical aspect is the impact of CO_2 at depth on fault-seal integrity. The injection well will undergo completion to ensure hole integrity, to guarantee that the CO_2 is injected into the correct reservoir interval, and that the interval of interest can be traced to other well bores. Workover of any existing production wells and using idle wells for monitoring will be employed as needed to maintain seal integrity of the reservoir while minimizing project costs. Surface access will be obtained to facilitate the installation of shallow, vadose-zone monitoring wells to validate that no CO_2 has infiltrated from the injection level to the shallow-drinking-water or surface-water zones. The reservoir container will be characterized to determine optimal injection criteria as well as logging responses expected during injection in monitoring and producing wells. The core analysis performed will address these issues.

FT1 Operations

Injection operations will be similar to those performed at the Frio Brine Pilot site. At the site, the CO_2 will be repressurized to the required reservoir conditions utilizing injection equipment and processes. The experiment is planning on injection of up to 15,000 tons of CO_2 over a five-month period at 3,000 tons per-month. Longer-term considerations of using low-pressure pipeline facilities at specific sites will be considered where practical but are not anticipated to be economically feasible for the field test, only for post-test, full-injection implementation.

In the stacked storage experiment, SECARB will build on the Frio Brine Pilot experience to define effective monitoring strategies for the interaction of CO_2 injection with faults;

distribution of pressure in the near and far field during and after injection; and impact on fluid flow and deformation. It is critical to conduct a successful CO_2-EOR project in order to fund injection at a scale sufficient to support the monitoring strategy. The following tools will be assessed prior to field activity, and those proving viable will be fielded:

- a cased, low-angle observation bore hole that crosses the sealing fault and accesses CO_2 plume development and sweep;
- pressure, temperature, and environmental management tools permanently installed with the casing of this observation well;
- a suite of open- and cased-hole logs repeated through time in all available well bores to monitor plume evolution and observe any changes above the injection zone;
- an array of tilt meters on the surface and/or down hole;
- injected suites of partitioning and nonpartitioning tracers in brine and CO_2 to track fluid interactions and migration;
- near-surface monitoring for gas composition and tracer; and
- ecosystem monitoring for any impact related to CO_2 leakage.

In addition, SECARB will assess the feasibility of detecting CO_2 using down hole, crosswell or surface geophysics in the selected well configuration. Three groups of instrument designers have extensive experience: Lawrence Livermore National Lab; Lawrence Berkeley National Lab; and the Diagnostic Instrumentation Analysis Laboratory (DIAL) at Mississippi State University (MSU).

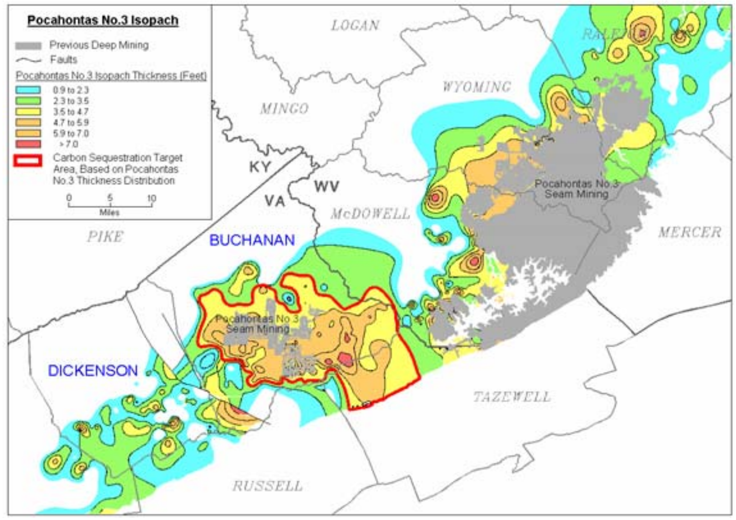
SECARB will determine the preferred method of transporting CO_2 to the selected field. Two options include compressed liquid via truck or barge and low-pressure gas via existing pipeline. CO_2 will be an essentially pure commercial product. SECARB will continue to evaluate emerging capture options, both in industrial and power plant settings, which are critical to long-term applications of the technology.

Injection of CO_2 (a key milestone) will start only after an environmental review has been conducted. The project plan calls for a minimum of 7,500 tonnes of CO_2 and up to 15,000 tonnes of CO_2 for injection. The injection operator will maintain the safety environment for the project and will collect all injection data as to volume, rate, and pressures utilized. This information will validate injection and production models for tracking injection fronts and production efficiencies across the field. SECARB will perform post-injection assessments. Information collected will be utilized in validating injection and producing models for tracking injection fronts and production efficiencies across the field. Monitoring will continue for an extended time after injection, both in the subsurface to determine storage of the CO_2 and at the surface to ensure that escape of CO_2 from the subsurface injection area does not occur. During the course of the project, the SECARB team will engage local media, interested governmental bodies, and local residents.

FT1 Closeout/Reporting

At the conclusion of the project, a post operation discussion of activities and results will be presented to DOE and other interested parties. Discussions will continue with the local operator on continued use of the field site for experimentation on other possible projects and to determine whether EOR aspects were successful enough for the operator to move to a full-phase recovery project. If this does occur, then interaction with the operator and supplier of CO_2 for longer range storage projects will continue.

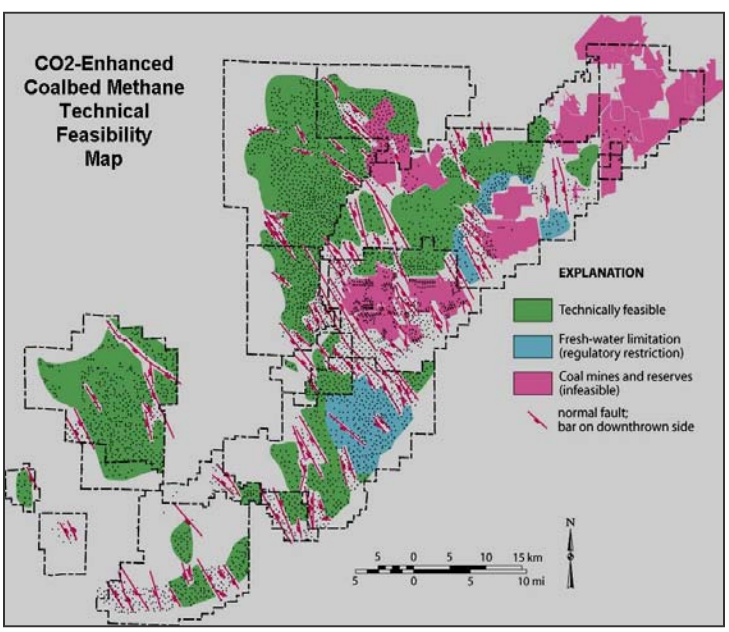
Figure 29. Pocahontas No. 3 Seam Thickness Isopach



Field Test 2 (FT2): Coal Seams Action Plan

The action plan focuses on coal seams with high methane content and unminable coal seams in the vicinity of existing coal fields extending from the Appalachian range (Karmis, 2005), southwesterly into the Black Warrior Basin (Pashin, 2004) and towards the Gulf Coast. This field test will demonstrate CO_2 injection for ECBM in the southeastern United States. Also, this field test will investigate CO_2 sequestration in unminable coal seams and address a breakthrough concept for sequestering a full range of coal-fired power plant emissions. Two field test areas have been identified, one in the Central Appalachian Basin of Virginia, West Virginia, and Kentucky and one in the Black Warrior Basin of Alabama. These areas are shown in Figure 29 and Figure 30 respectively.

Figure 30. Sequestration Target Areas for the Warrior Basin in Alabama



FT2 Project Definition

Geological assessment of coal seams and GIS development will continue. The Black Warrior Basin has been assessed in detail; however, similar assessments are lacking for some areas of the Central Appalachian Basin and for the coal fields of the Alabama thrust belt. Regional characterization activities will focus on sequestration potential of CBM reservoirs in the Cahaba and Coosa coal fields of the Alabama thrust belt, where no assessments of sequestration and ECBM potential are available. Regional geologic mapping for the Central Appalachian Basin will be expanded into neighboring counties in Kentucky and southern West Virginia.

SECARB will review characterization study results to determine optimum sites for core hole drilling and testing for pilot injection of CO_2. Approximately four well sites in both Central Appalachia and Alabama will be reviewed for possible selection as pilot sites. The results of geological characterization will be used to select the final test sites and to determine the precise well design and monitoring plan.

Reservoir modeling is an important component in understanding the mechanisms at work in carbon sequestration within coal seams. As such, the process will require the gathering of production history and detailed geologic information for each of the prospective pilot locations. A history match will be synthesized from these data. Multiple sensitivity runs then will be conducted concerning the injection of CO_2 (rate, pressure, and duration) and production controls at offset producers (rate, pressure), which should contribute to the design aspect of the pilot by providing estimates of the necessary CO_2 volumes, expected operating conditions, and a baseline expectation.

The public outreach and education activities for the Coal Seam Project should be initiated early and span the entire schedule, beginning with the assembly of an advisory committee at the start of the project that will include a broad range of stakeholders, including gas producers, utilities, regulators, and landowners. A vigorous technology transfer program will be conducted and will include development of a project website, presentations at technical meetings, and publications. A local outreach program in both Alabama and Central Appalachia will develop a grassroots group to enlighten citizens in the area on the positive benefits the sequestration program offers. A speaker's bureau will be created to engage and educate elected officials (local, regional, state), chambers of commerce, civic organizations, and educational communities through printed publications and PowerPoint presentations.

FT2 Design

Four types of reservoir modeling efforts provide the basis for design:

- review of the selected primary injection site's basins;
- rigorous history matching and assessment of the preferred CO_2 injection sites;
- mid-course reservoir modeling to assess the performance of the project against expectations; and
- post-project history matching and performance prediction of the CO_2 sequestration pilots and their implications to CO_2 storage in the basins.

After the locations of the test sites are determined, three core holes will be drilled around each production well and the specific pilot design will be determined on the basis of the baseline reservoir models.

FT2 Implementation

This program will make use of existing CBM wells. Therefore, the principal construction requirements under this program will be the drilling of core holes and the installation of monitoring apparatus. Field work will not begin until an environmental review has been completed. Three core holes will be drilled around the production well immediately after the location of the test site is finalized. These holes will be about 75 to 150m from the production well, and the precise locations will be determined on the basis of the baseline reservoir models. After the cores are removed for analysis, the core holes will be converted into monitor wells. A similar monitoring design was employed at the Rock Creek test site in the Black Warrior Basin, which was used to develop CBM completion technology (Spafford and Stubbs, 1989; Koenig, 1989). Isolation packers and slim hole monitoring equipment will be installed to observe reservoir pressure and gas composition. Shortly thereafter, shallow slant holes will be drilled and monitoring equipment will be installed to analyze gases in near-surface fractures.

Risk analyses will be performed and include review of the feasibility of the proposed pilot tests and assessment of environmental risks. Integration of geologic, geophysical, laboratory, reservoir, and production data will be necessary to complete this task. Monitoring and verification implementation will focus on two approaches: (1) deep well monitoring; and (2) shallow subsurface monitoring. To prepare for field testing, the core holes will be converted to deep monitor wells by an oilfield service company, and three shallow wells will be drilled for shallow monitoring in the Black Warrior Basin pilot. Baseline data will be collected for a minimum of three months before injection-falloff and production testing begins. Monitoring equipment will be installed in the shallow wells to monitor CO_2 levels. Baseline data on natural CO_2 levels will be measured for at least three months prior to deep well testing. Any required leases, surface owner agreements, state drilling permits, and Class II permits from the EPA will be obtained prior to implementation.

FT2 Operations

A sequence of parallel tests will be performed in Alabama and Central Appalachia in order to allow proper evaluation of each basin. These tests will be staggered to allow for proper funding and minimize replication among the proposed pilot tests. Pilot project operations will constitute a series of injection-falloff and production tests similar to those performed by the Alberta Research Council (Law, 2004). The total amount of CO_2 required for each injection program is estimated to be 1,000 tons. However, higher injection volumes are anticipated for the horizontal multi-lateral injection pilot in the Central Appalachian region. Reservoir pressure and gas composition will be monitored in the deep monitor wells throughout the injection testing. Deep monitoring will continue for at least three months after the injection tests are completed. Similarly, gas composition will be monitored in the shallow monitor wells at the Alabama site throughout the injection tests, and shallow monitoring also will continue for at least three months after the injection tests are completed to ensure that no leakage occurs.

Injection operations at each of the proposed coal seam test sites will comprise a series of injection-falloff and production tests similar to those performed by the Alberta Research Council in Canada and China (Law, 2004). Prior to injection, a production and pressure-buildup test will be performed in three separate coal zones to analyze pressure response and permeability near the production well. Next, a 10- to 15-ton slug of CO_2 will be injected into each coal zone to determine the pressure-falloff response of the reservoir to CO_2, and then a second set of production tests will be performed. After this, a larger slug of up to 100 tons of CO_2 will be injected and pulsed injection tests performed. Additional injection tests will follow this step, and the size and timing of these tests will be determined on the basis of the initial results of production and injection-falloff testing. A final production test will be performed to analyze changes in reservoir properties after the injection tests are complete. The total amount of CO_2 required for each injection program is estimated to be 1,000 tons. However, the test procedure and CO_2 requirement may be changed somewhat for the multi-lateral horizontal test after initial modeling is complete.

Monitoring and verification will focus on deep well monitoring and shallow subsurface monitoring. After the three core holes are drilled at each test site, they will be converted into deep monitor wells. Packers will be installed to isolate three separate coal zones. Slim hole equipment for observing reservoir pressure and gas composition will be installed between the isolation packers to monitor reservoir pressure and gas composition (CO_2 and CH_4). Baseline data will be collected for a minimum of three months before injection-falloff and production testing begins, and data will continue to be collected during the well testing and for at least three months after the testing is completed. Pressure response and gas composition will be mapped using the data from the observation wells, and reservoir models will be refined on the basis of the data.

Southern Company Services (SCS) will perform surface and shallow subsurface monitoring in Alabama consisting of approximately 30 surface sampling stations and three shallow wells that will be drilled directionally. Infrared gas analyzers with accumulation chambers will be used to measure CO_2 flux using the methods of Ghafurian et al. (1998) and Galdiga and Greibrokk (2000). The three wells will be drilled into bedrock below the soil zone to analyze gases in fractures and to minimize false-positive CO_2 readings caused by bacterial action within the soil profile. Baseline data on natural CO_2 levels will be measured for at least three months prior to deep well testing, and testing will continue for at least eight months after the injection-falloff and production tests are completed. One shallow monitor well will be drilled near the production well to test for leakage near the injection site, another will be installed above the main hydraulic fractures that extend laterally from the production well, and a third will be installed in a location remote to the production well and other monitor wells.

The principal risks associated with the injection experiments are leakage of CO_2 and dilution of CH_4 with CO_2 in nearby production wells. The small amount of CO_2 required for the injection tests will minimize risk by limiting the probability of leakage. Also, the small amount of CO_2 to be injected under this program should not travel more than 150 meters from the well bore and thus should not affect the quality of gas produced in nearby wells. The deep monitoring program for gas composition will be sufficient to determine if communication of gas between coal zones occurs. The shallow monitoring program, similarly, will be used to determine if seepage of injectate at the surface is a problem at the Alabama pilot. If surface seepage is a problem there, then injection rates will be reduced, or the injection tests will be terminated. If communication between coal zones occurs, injection pressures and volumes will be adjusted to minimize communication.

CO_2 will be purchased from a commercial source. Transportation to the well site will be by tanker trucks, which hold up to 30 tons of CO_2. The CO_2 will be warmed to surface temperature and injected directly from the trucks. The CO_2 that is used in the injection tests will be relatively pure and contain no significant impurities that will impact the project results.

A sequence of parallel tests will be performed in Alabama and Central Appalachia in order to allow proper evaluation of each basin. These tests will be staggered to allow for proper funding and minimize replication among the proposed pilot tests. Pilot project operations will constitute a series of injection-falloff and production tests similar to those performed by the Alberta Research Council (Law, 2004). The total amount of CO_2 required for each injection program is estimated to be 1,000 tons. However, higher injection volumes are anticipated for the horizontal multi-lateral injection pilot in the Central Appalachian region. Reservoir pressure and gas composition will be monitored in the deep monitor wells throughout the injection testing. Deep monitoring will continue for at least three months after the injection tests are completed. Similarly, gas composition will be monitored in the shallow monitor wells at the Alabama site throughout the injection tests, and shallow monitoring also will continue for at least three months after the injection tests are completed to ensure that no leakage occurs.

FT2 Closeout/Reporting

The Coal Seam team will interpret the results of deep and shallow monitoring and refine reservoir models using the injection-falloff and production data and obtain a history match. A base forecast will be supplied to understand the potential movement of CO_2 over geologic time. Various sensitivity parameters will be reviewed, such as caprock permeability and vertical permeability within the coals to aid in the understanding of long-term storage and migration of CO_2 within coal seams. The results of injection testing will identify best practices for CO_2 sequestration, vertical versus horizontal well injection efficiencies, ECBM, monitoring, and regulation. Well tests and model results will be used to revise procedures for assessing sequestration capacity and ECBM potential in other coal basins. The proposed injection tests for CO_2 constitute an early step in realizing the acid-gas sequestration potential of coal. Modeling efforts and analysis of regulatory factors also will explore the possibility of sequestering multiple acid gases in coal, a breakthrough technology with the potential for low cost, permanence, and large global capacity.

Field Test 3 (FT3): Saline Formation Action Plan

Field Test 3 focuses on the ultimate goal of locating suitable geologic sequestration sinks in proximity to large coal-fired power plants. Funds will be used specifically for investigating the geologic formations in proximity to EPRI's proposed Test Center. The site is located along the southern boundary of the Mississippi Salt Basin. The Test Center team will assemble the available deep well logs, core analyses, and other geological data to build a geologic and reservoir model. The team will use its COMET2 reservoir simulator to estimate CO_2 injectivity plus long-term CO_2 storage capacity and fate. The team also will run the models for a longer time period to fully assess the CO_2 storage potential of the saline aquifers in this area.

FT3 Project Definition

The Test Center team will specify the well pad and infrastructure criteria, prepare the drilling, casing and completion plan, define the surface facility requirements, identify the reservoir characterization and testing plan for the injection and monitoring wells, and conduct numerous other pilot test site planning and preparation tasks. The team will: (1) support Southern Company and the local plant management involved in the test site project with initial information and distribution materials on the proposed project; and (2) work with Southern Company to prepare an action plan for informing the public and gaining their acceptance.

The FT3 team will build a detailed geological and reservoir model of the proposed test site, including conducting a sequence of reservoir simulations to estimate injectivity, storage capacity, and the long-term fate of injected CO_2. The project will assemble the available deep well logs, core analyses, and other geological data to build a geologic and reservoir model of the proposed saline aquifer test site. The Test Center team will use the COMET2 reservoir simulator to estimate the CO_2 injectivity and the long-term CO_2 storage capacity and fate of the injected CO_2 of the site. The team will run the model to match the injection rate and flow performance of CO_2 injection at the test site to conduct a "history match" that will provide confidence in the CO_2 storage properties of the Eutaw formation in the plant area. Next, the model will be executed for much longer time periods and for a larger geographic area to predict the CO_2 storage potential of the Eutaw saline aquifer in this portion of the SECARB region.

To help define the CO_2 storage potential of the area, a sequence of four reservoir modeling efforts will be conducted during Phase II. These will be:

- initial "screening modeling" to verify the selection of the primary site;
- rigorous assessment of the preferred CO_2 injection site after obtaining actual reservoir data from the slim hole monitoring well;

- numerous sensitivity runs to establish injectivity and storage; and
- mid-course reservoir modeling to assess the performance of CO_2 injectivity and flow prediction.

FT3 will assist Southern Company and the local plant management with initial information and distribution materials on the proposed project. FT3 will work with Southern Company to clearly define roles for Southern Company's management staff, SECARB, and the pilot project plant staff for informing the public and gaining their acceptance. The team will provide periodic updates of the project to Southern Company and SECARB staff in a form that can be readily submitted to the public at large. FT3 will design plans using insights from the successful public outreach and education efforts by the DOE/NETL sponsored BEG Frio saline aquifer project in Texas and the American Electric Power's Mountaineer CO_2 sequestration project in West Virginia. FT3 also will ensure that the project complies with the public involvement requirements set forth for NEPA and regulatory permitting. In addition to providing information to the public using local newspapers and media advertising, FT3 will help Southern Company hold public education programs at libraries, schools, and local businesses and provide information to and personal visits with local and state officials interested in the saline aquifers CO_2 sequestration project in the SECARB region.

FT3 Design

FT3 will procure and transport approximately 3,000 tons of CO_2 and inject it over 30 days of operation. The total volume of CO_2 injected will depend on the costs which are projected to be $100 per ton. The Test Center team will set forth the CO_2 storage and monitoring protocols for the saline aquifer's field test site including, as appropriate, "shooting" of baseline and subsequent seismic, pressure, and fluids sampling by the observation wells and the linkage of reservoir simulation-based projections of the movement and fate of CO_2 with actual observations. The MMV protocol description includes the costs of installing and operating each protocol. Test site permitting will ensure that NEPA, EA and EIS requirements are met and that valid permits are obtained. For the saline aquifer test site, the team will (1) provide a roadmap for permitting saline aquifer test sites in the region; (2) consult with federal and state regulatory permitting agencies for guidance and information; (3) satisfy the local, state, and federal permitting requirements to conduct the project, including transportation, storage, monitoring, and risk assessment; and (4) track changes to the regulatory requirements for sequestration in the region.

FT3 Implementation

The first step will be to conduct an environmental review, followed by characterization of the reservoir. A slim hole reservoir characterization well will be used to acquire subsurface data to conduct the detailed pre-injection well drilling characterization of the test site. Later, this well will be used to provide future reservoir access for monitoring and observing the flow and storage of CO_2 in the Eutaw saline aquifer. As part of the slim hole well reservoir characterization effort, a full suite of geophysical logs will be obtained, pressure transient testing on reservoir zones of interest will be conducted, and the formation and overburden stress evaluated.

The well logging will provide vital information on the porosity and net reservoir thickness of the Eutaw formation in the test site area, which is essential for estimating the CO_2 storage potential in the test site area. The pressure transient testing will provide a first-order estimate of the reservoir permeability necessary for calculating CO_2 injectivity in the test site area. The confining stresses of the shale formations adjacent to the primary CO_2 injection zones will be evaluated to provide an assessment of the competence of the reservoir seal.

After drilling, logging, and testing of the slim hole well in the Eutaw formation, the next step will identify the specific location and prepare the well pad for the CO_2 injection well. This process will involve examining the surface characteristics of the area, identifying the need for new roads or alternative site access, and establishing the size, disposal requirements, and environmental impacts of establishing the well site. It also will involve arranging for site clearance, well pad construction, and protective fencing. The final step is to procure the well drilling, well completion, and surface equipment for the test site.

Site-specific reservoir characterization will be conducted beginning with a slim hole reservoir characterization of wells along with well testing and analysis to acquire detailed subsurface data. A suite of geophysical logs will be obtained, and pressure transient testing on reservoir zones of interest will be conducted. The confining stresses of formations adjacent to the primary CO_2 injection zones will be evaluated. The Test Center team expects three months for site preparation, well drilling, and installation of facilities. The team will define and conduct the work designed to establish the baseline conditions for the field test site, including a high resolution 2-D seismic survey, soil sampling, reservoir fluid sampling, and the characterization of the reservoir seal and bounding layers.

FT3 Operations

As part of this effort, the FT3 team will specify the CO_2 injection and testing plan for the injection and monitoring wells. The current plans are to inject approximately 3,000 tons of CO_2 and to observe its movement and storage in the saline aquifer formation. The team will review these plans with the outside experts to ensure that the injection and monitoring expectations are sound. Particular attention will be given to avoiding and reducing well bore corrosion problems from the acidic CO_2 and water solution during the injection of CO_2.

The FT3 team will set forth the CO_2 storage and monitoring protocols for the saline aquifers field test site. This will include, as appropriate, baseline and subsequent seismic surveys, pressure, and fluids sampling by the observation wells, and the comparison of reservoir simulation-based projections of the movement and fate of CO_2 with actual observations. The team will define and supervise the implementation of work designed to establish the baseline conditions for the field test site. This will include conducting a high-resolution 2-D seismic survey, soil sampling, reservoir fluid sampling, and the characterization of the reservoir seal and bounding layers. The current plan is to shoot two ten-mile 2D seismic lines over the field test site, to provide the important "baseline." This will be followed by shooting two additional ten-mile seismic lines after CO_2 injection to track the movement and storage of the CO_2. The fluid sampling plan will include taking fluid measurements in the monitoring well to gain an understanding of CO_2 saturation in the field test site area.

Risk analysis will include examination of the pilot project operation and assessment of future environmental risks. This task will be conducted and performed as an EA, reviewing the potential risks relevant to a given pilot site(s). Integration of geologic, geophysical, laboratory, reservoir, and production data will be necessary to complete this task. Highlights of this analysis should consider caprock integrity, quality of stored CO_2, movement profile, MMV, and duration of storage, with significant portions of this information being derived from the reservoir modeling. More specifically, this task will review and assess the potential economic and environmental risks involved in pilot and large-scale CO_2 injection projects due to contamination of offset wells, carbonic acid induced corrosion, contamination of groundwater or other horizons, and possible facility incidents. Land, regulatory, safety, operational, gas processing, and logistical issues that could present obstacles to pilot or large-scale implementation projects also will be reviewed.

The FT3 team's preliminary plan is to purchase 3,000 tons of CO_2 and transport it under pressure to the test site. While we have yet to establish the source of CO_2, FT3 has identified a number of viable options, including ethanol plants, refineries, fertilizer plants, and gas processing plants in the area. The Test Center team is familiar with Denbury's plans to extend their CO_2 transportation line south. This provides the test site a back-up source of CO_2 should industrial sources of CO_2 not be available or too costly.

Based on the volume of CO_2 to be injected, the test site will operate actively for 30 days, with monitoring and passive operations to follow. Selected MMV protocols, including a second high resolution 2-D seismic survey, will ensure that the sampling plan, frequency and number of samples taken, and the overall operations of MMV at the saline aquifer test site meet the protocol design. Mid-course reservoir modeling will assess the performance of the project and its implications to CO_2 storage in the basins.

FT3 Closeout/Reporting

The Test Center team will provide FT3 closeout/reporting to establish the economic and CO_2 storage implications for the overall SECARB region learned from the performance of the test site. The economic model will be used to extrapolate the results from the pilot to basin-scale.

Conclusion

The Southeast Regional Carbon Sequestration Partnership successfully completed the majority of its Phase I of the program work by September 30, 2005 and compiled its findings under a no-cost extension that remains open until August 31, 2006. Information received as of June 15, 2006, was used to prepare the Draft Final Report.

The Partnership's Phase I work was guided by the following objectives:

- Supporting the United States Department of Energy's (DOE) Carbon Sequestration Program by promoting the development of a framework and infrastructure necessary for the validation and deployment of carbon sequestration technologies;
- Supporting the President's Global Climate Change Initiative goal of reducing greenhouse gas intensity by 18 percent by 2012; and
- Evaluating options and potential opportunities for regional carbon dioxide (CO_2) sequestration.

The Partnership developed a framework and infrastructure necessary for the validation and deployment of carbon sequestration technologies. This was accomplished by addressing CO_2 storage and capture, CO_2 transport, regulatory, permitting, communication and outreach, public acceptance, monitoring and verification and environmental efficacy of sequestration within the Southeast region.

SECARB accomplished its objectives by:

- Defining similarities in the eleven-state region;
- Characterizing the region relative to sources, sinks, transport, sequestration options, and existing and future infrastructure requirements;
- Identifying and addressing issues for technology deployment;
- Developing public involvement and education mechanisms;
- Identifying the most promising capture, sequestration and transport options; and
- Developing Action Plans for implementation and technology validation.

Problems Encountered

No unforeseen problems were encountered during the SECARB Phase I program.

Significant Accomplishments

The Southeast Regional Carbon Sequestration Partnership achieved significant accomplishments during the two-year program period. The team conducted a study and workshops for an eleven-state region. CO_2 sources, sinks and transport requirements were identified and entered into a geographic information system. An outreach plan was developed to engage stakeholders in the process of identifying and implementing regional opportunities for CO_2 sequestration. Literature searches, including exposure/dose response, were utilized to assess environmental risk due to sequestration activities. Environmental efficacy was confirmed through the development of measurement, monitoring, and verification protocols. The evaluation of storage options considered regulatory and permitting requirements, MMV requirements, public acceptance, accounting framework (including Section 1605(b) of EPAct).

The SECARB team identified the similarities of CO_2 sources, sinks, permitting considerations, partners and other features within the region to include an inventory of major sources by SIC or other designation; an inventory of potential sinks by terrestrial and geological designation; permitting structures by state; and the recruitment of active partners.

The region was characterized relative to sources, sinks, transport, sequestration options, and existing and future infrastructure requirements. Information gathered during Phase I characterization was archived in a relational database and GIS.

SECARB utilized information gathered in the regional assessment to identify the most promising regional opportunities for capture, transport and sequestration of CO_2. Further, the team assessed and validated the most promising emerging technology developments and identified those minor modifications required to fit the technology to the regional application.

Lastly, Action Plans were prepared to implement a framework leading to small-scale regional technology validation field tests. The Partnership considered cost-effective approaches that provide flexibility for assessing multiple candidate technology options. Several Action Plans were developed on the topics of capture options; transportation activities; sequestration options; commercial use; public involvement, public acceptance and education; and regulatory, permitting and accounting frameworks. Additionally, the SECARB team provided the framework for a regional strategy for demonstration and wide-scale deployment of the most promising greenhouse gas mitigation strategies identified for the region.

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To assist the reader, several references are included as footnotes within the text of the document. The remainder are found in the following list.

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List of Acronyms and Abbreviations

ARI	Advanced Resources International
CBM	Coal Bed Methane
CO_2	Carbon Dioxide
COOP	Carbon Offset Opportunity Program
CRDS	Cavity Ringdown Spectroscopy
DEM	Digital Elevation Model
Department	United States Department of Energy
DIAL	Diagnostic Instrumentation and Analysis Laboratory
DOE	United States Department of Energy
DOT	United States Department of Transportation
ECBM	Enhanced Coal Bed Methane
EGR	Enhanced Gas Recovery
EOR	Enhanced Oil Recovery
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
GCCC	Gulf Coast Carbon Center
GHG	Greenhouse Gas
GIS	Geographical Information System
GNIS	Geographic Names Information System
GSA	Geologic Survey of Alabama
GSWG	Geologic Sequestration Working Group
IOGCC	Interstate Oil and Gas Compact Commission

LIBS	Lazer Induced Breakdown Spectroscopy
LGS	Louisiana Geological Survey
MIT	Massachusetts Institute of Technology
MMA	Marshall Miller and Associates
MMRI	Mississippi Mineral Resource Institute
MMV	Monitoring, Measurement and Verification
MSU	Mississippi State University
NARSAL	Natural Resources Spatial Analysis Laboratory
NATCARB	National Carbon Database
NETL	National Energy Technology Laboratory
NLCD	National Land Cover Dataset
NOAA	National Oceanic & Atmospheric Administration
NPP	Net Primary Productivity
O_2	Oxygen (pure)
OPS	Office of Pipeline Safety
Partnership	Southeast Regional Carbon Sequestration Partnership
PEIS	Programmatic Environmental Impact Statement
PSI	Pounds Per Square Inch
RCSP	Regional Carbon Sequestration Partnership
R&D	Research and Development
SDWA	Safe Drinking Water Act
SECARB	Southeast Regional Carbon Sequestration Partnership
SLC	Southern Legislative Conference
SSEB	Southern States Energy Board
STATSGO	State Soil Geographic
TVA	Tennessee Valley Authority
TX BEG	Texas Bureau of Economic Geology
U.S. DOE	United States Department of Energy
U.S.	United States
UIC	Underground Injection Control
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
USDOE	United States Department of Energy
USDOT	United States Department of Transportation
USDW	Underground Sources of Drinking Water
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UT-BEG	University of Texas Bureau of Economic Geology
VRGGP	Voluntary Reporting of Greenhouse Gases Program
VT	Virginia Tech
WBCSD	World Business Council for Sustainable Development

WRI	World Resources Institute